The LHC: what's in store for the PDG?

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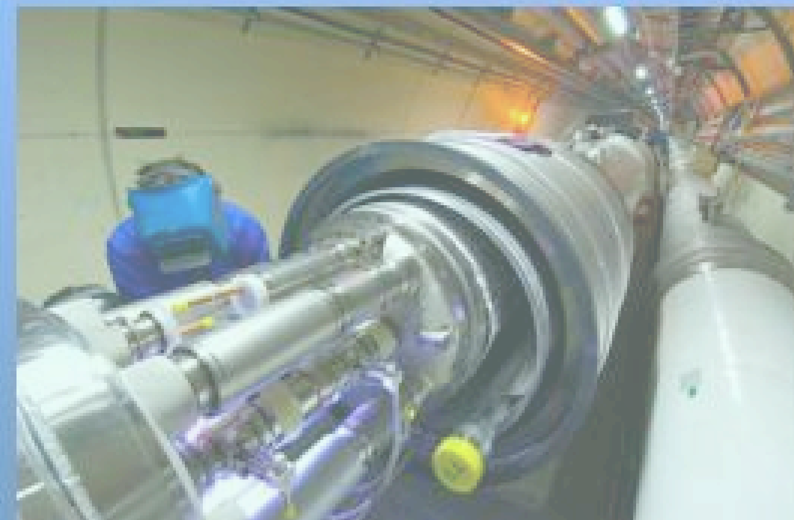
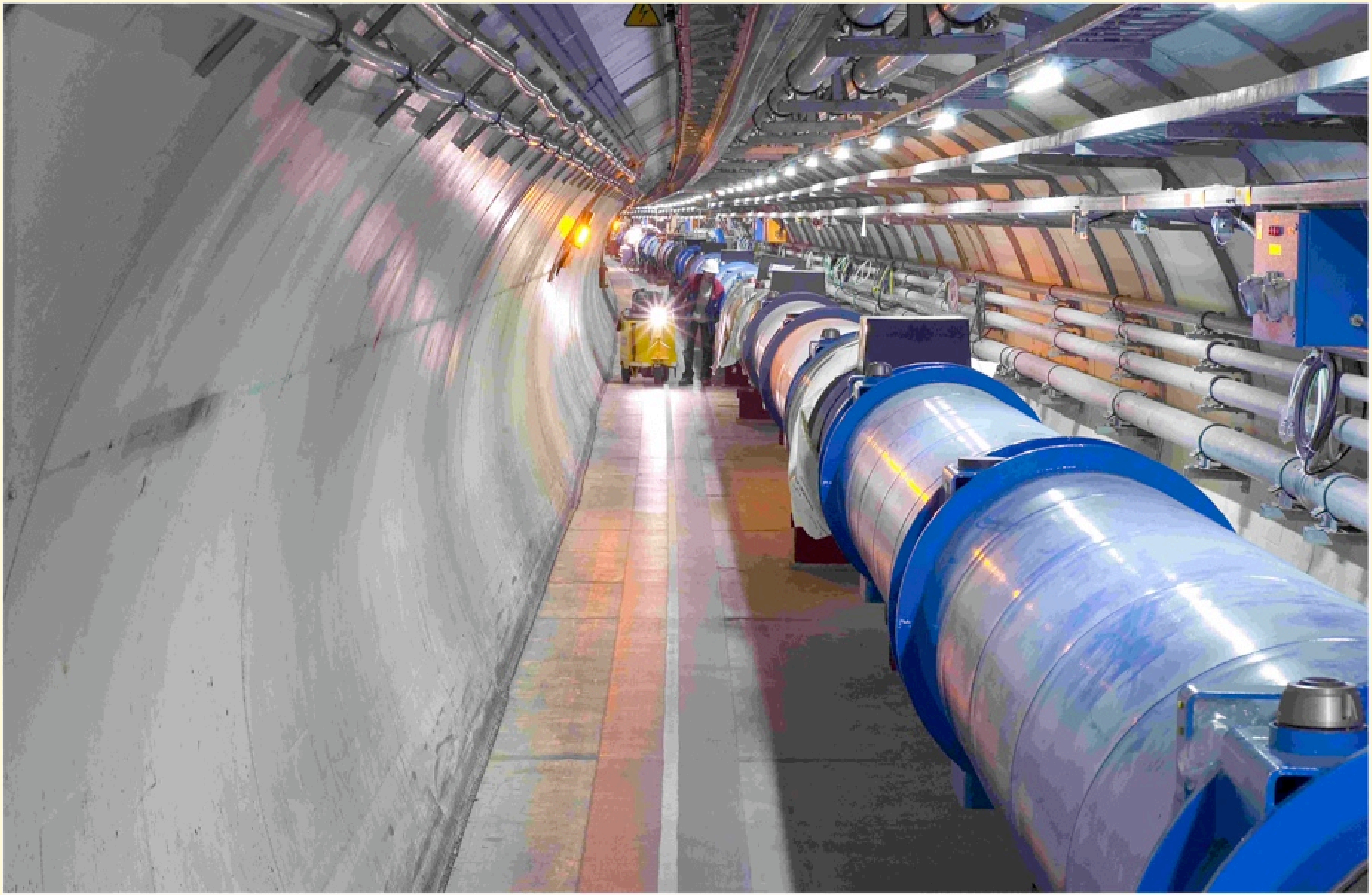


1957-2006 PDG particle data group

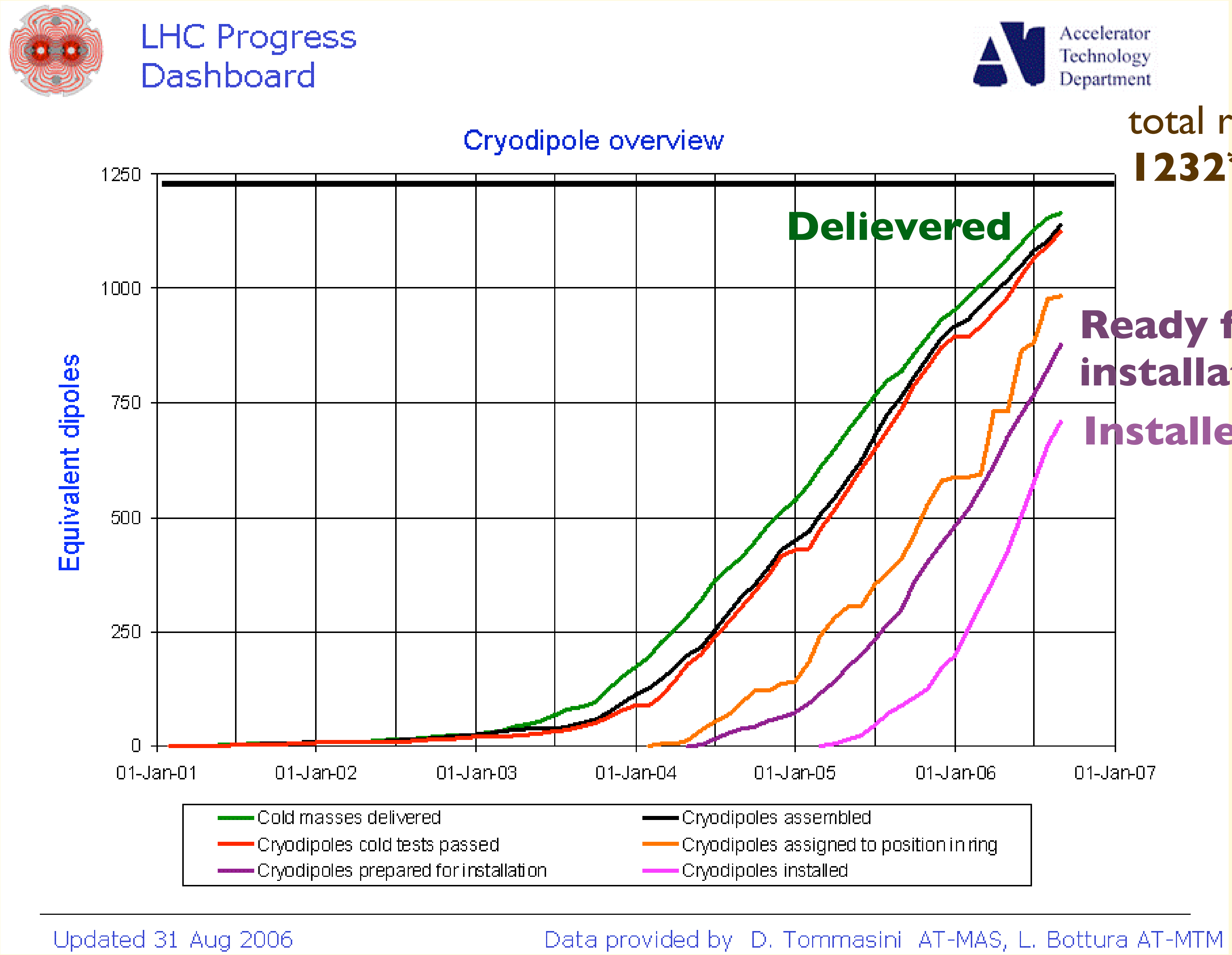
PDG 50th Anniversary Festivities

Berkeley, Sept 23 2006

THE LHC IS BECOMING REALITY!



Status of cryodipoles

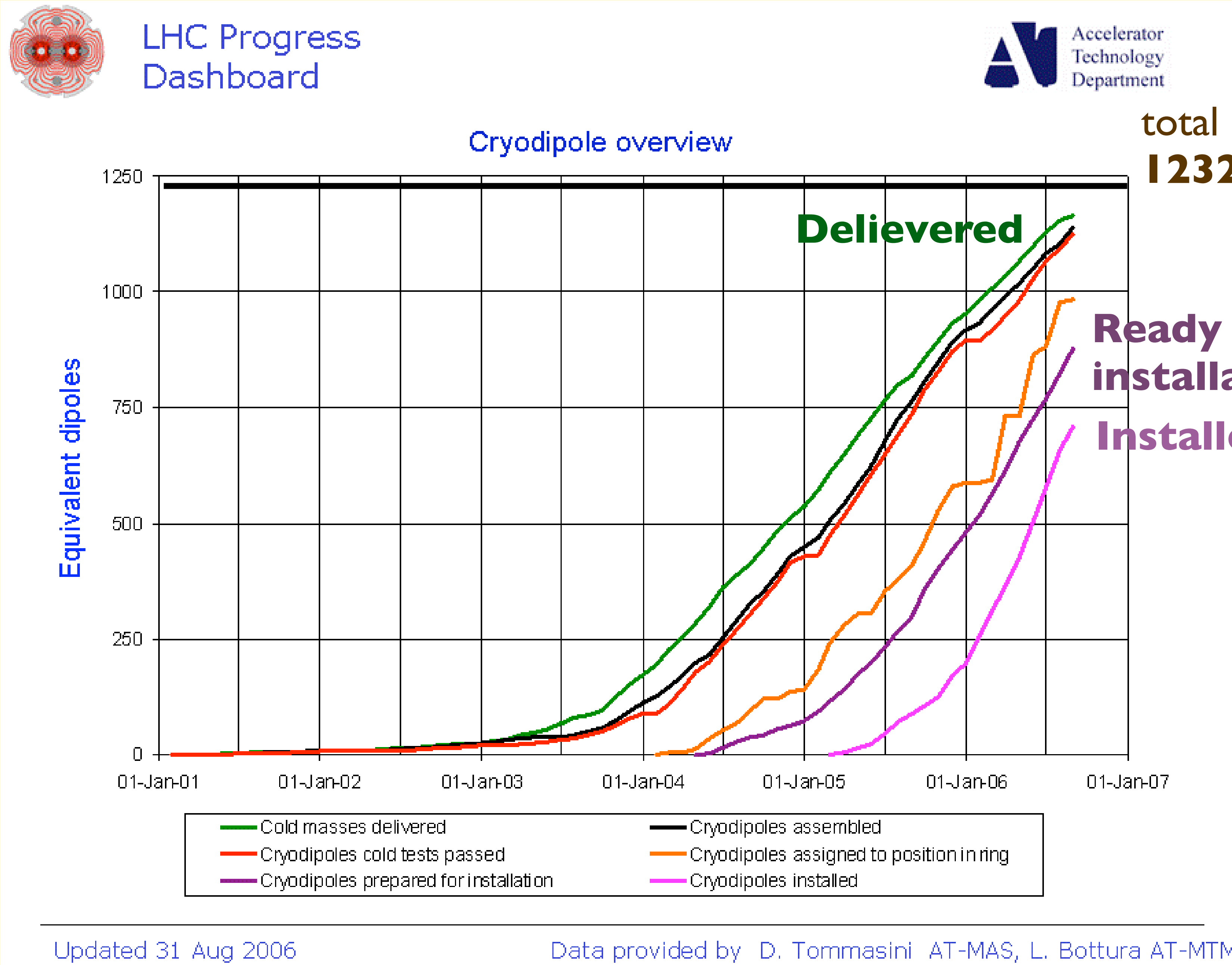


total required:
1232*

Ready for installation

Installed

Status of cryodipoles

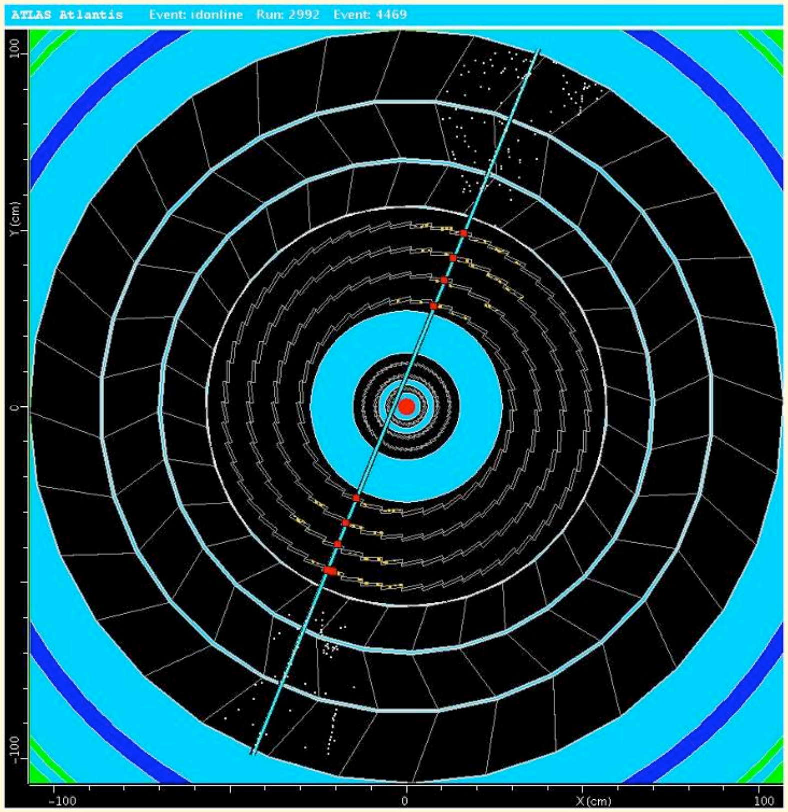


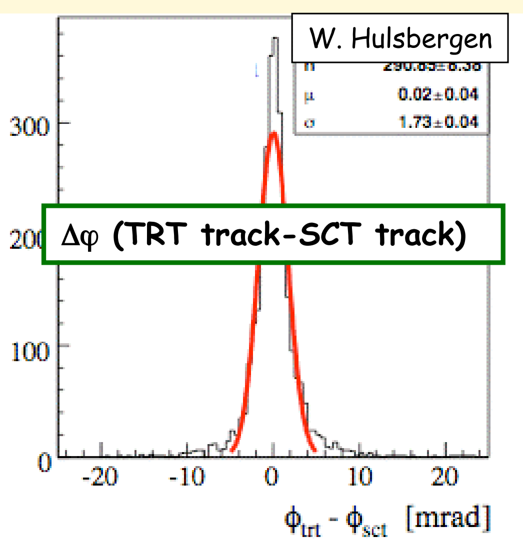
total required:
1232*

* ⇒ **1 for each page of RPP 2006 ... just a coincidence ??!!**

THE EXPERIMENTS ARE TAKING "*DATA*" !

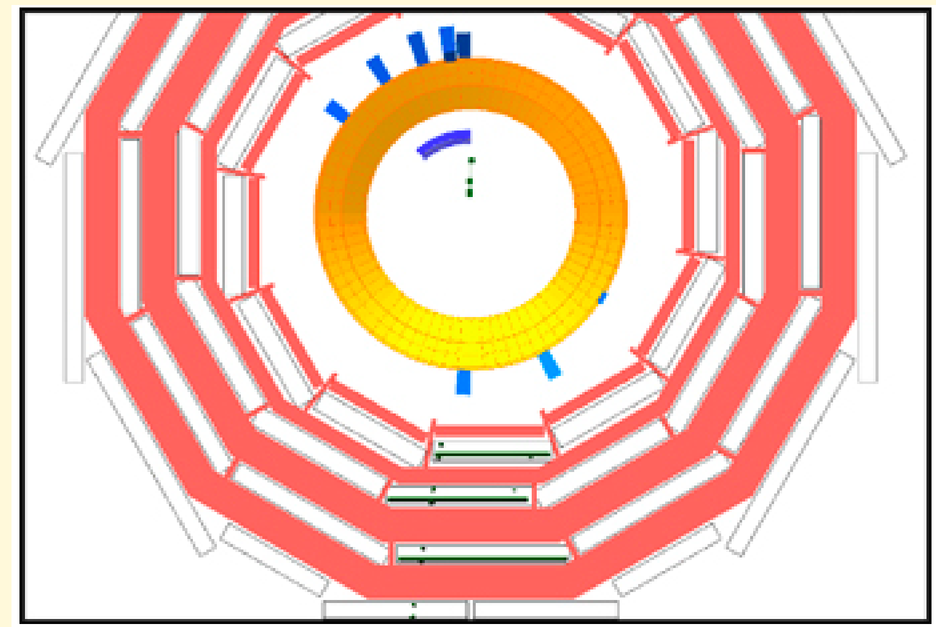
Cosmics through ATLAS's central tracker:





450K events

CMS solenoid @ 4Tesla !



One of the first events reconstructed in the Muon Drift Tubes, the Hadron Calorimeter and elements of the Silicon Tracker (TK) at 3 Tesla.

LHC schedule

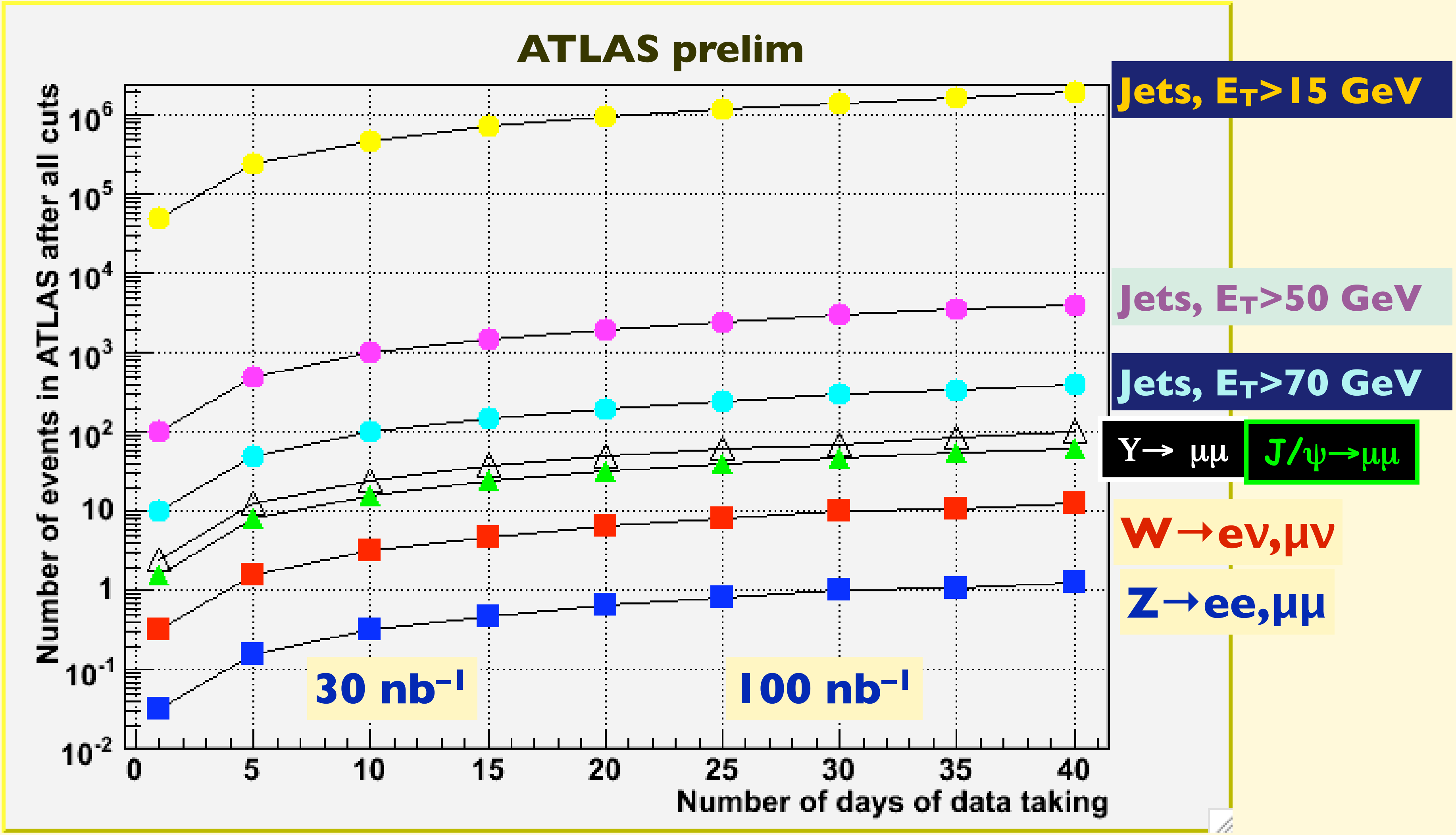
as of June 2006

2007:	March	Last magnet installed
	August 31	Machine and experimental halls closed, start beam commissioning
	Nov-Dec	First collisions; no ramp, $\sqrt{\mathbf{S}}$**=0.9 TeV, L~**$\mathbf{10^{29}\ cm^{-2}\ s^{-1}}$
2008:	Jan-Mar	Shut down, complete LHC hardware commissioning
	April	**→14 TeV,** $\int$**L ~ O(few** $\mathbf{fb^{-1}}$**) by end of the year**

PDG 50th Anniversary Festivities

2007 commissioning run

$\sqrt{S}$=900 GeV, L≈10^{29} cm^{-2} s^{-1}



From: F. Gianotti, ICHEP06

Rates include 30% data delivery and data taking efficiency, as well as trigger and analysis efficiencies

Only interesting entry for PDG: σ(pp) [tot, el]

As the energy and luminosity ramp up, the LHC will provide input to the PDG in different forms:

- Bread and butter physics: improvements, extensions, additions to current Listing entries
    - measurement of fundamental constants
    - measurement of fundamental properties of the SM
- Higgs discovery, completion of the SM
- Beyond the SM physics:
    - improving **limits** on new particles: bread and butter from the point of view of the PDG
    - interpret and incorportate in the RPP new **findings**: a new challenge for the PDG

SM physics

- measurement of fundamental constants:

	2006	LHC
δM_{top} (GeV)	2.2	~1
δM_W (MeV)	29	~20
$\delta \sin^2 \theta_W$	1.5×10^{-4}	$\sim10^{-4}$
$\delta\, \alpha_S / \alpha_S$	0.9%	—

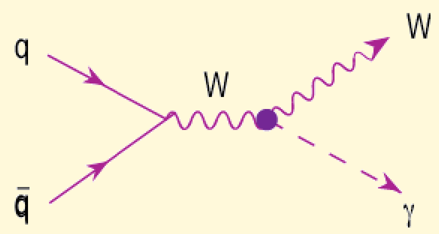
  - CKM
- SM tests:
  - anomalous gauge couplings (TGC, tbW: others better studied at LEP(2))
  - quark/lepton substructure
- SM dynamics
  - proton structure at high Q (including diffraction, etc)
  - structure of pp collisions (inclusive final states — a.k.a. MB — and underlying event in hard processes)

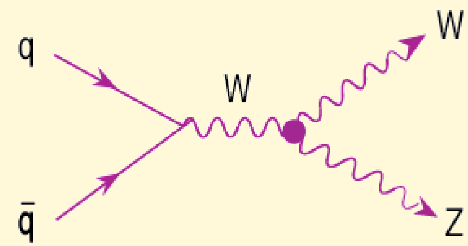
W mass syst's at LHC (60M $W \to l\nu$ / 10 fb^{-1})

Syst source	Atlas $\Delta M(W)$/MeV	
Stat	<2	
E-p scale	15	
Recoil model	5	
Lept ID	5	
ptW	5	
PDF	10	← Can improve with data
W width ($\Delta\Gamma=30$)	7	
QED effects	<10	← Can improve with data
Bg	5	
Energy scale	5	
Total	<25	← Can improve with data

Ex: Precise determinations of the self-couplings of EW gauge bosons

5 parameters describing weak and EM dipole and quadrupole moments of gauge bosons. The SM predicts their value with accuracies at the level of 10^{-3}, which is therefore the goal of the required experimental precision

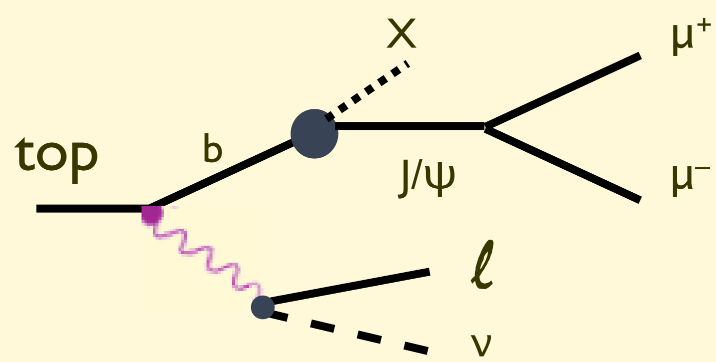




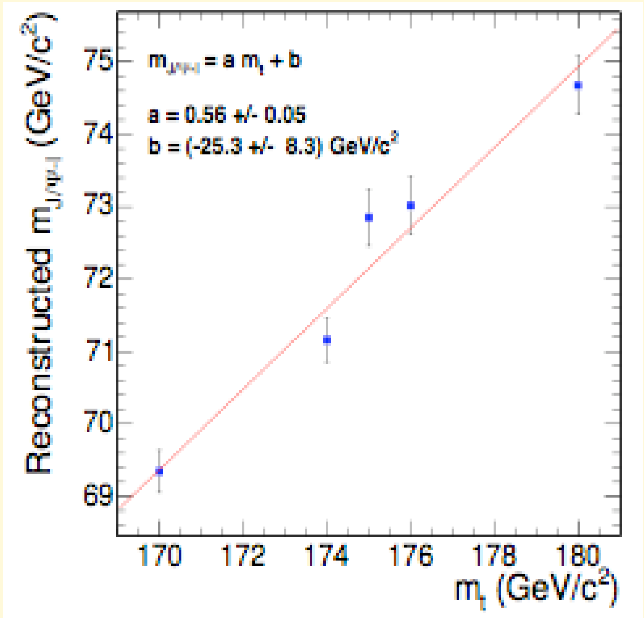
Coupling	14 TeV 100 fb^{-1}	14 TeV 1000 fb^{-1}	28 TeV 100 fb^{-1}	28 TeV 1000 fb^{-1}	LC 500 fb^{-1}, 500 GeV
λ_γ	0.0014	0.0006	0.0008	0.0002	0.0014
λ_Z	0.0028	0.0018	0.0023	0.009	0.0013
$\Delta\kappa_\gamma$	0.034	0.020	0.027	0.013	0.0010
$\Delta\kappa_Z$	0.040	0.034	0.036	0.013	0.0016
g^Z_1	0.0038	0.0024	0.0023	0.0007	0.0050

M_{top} from J/ψ final states

A. Kharchilava, '00



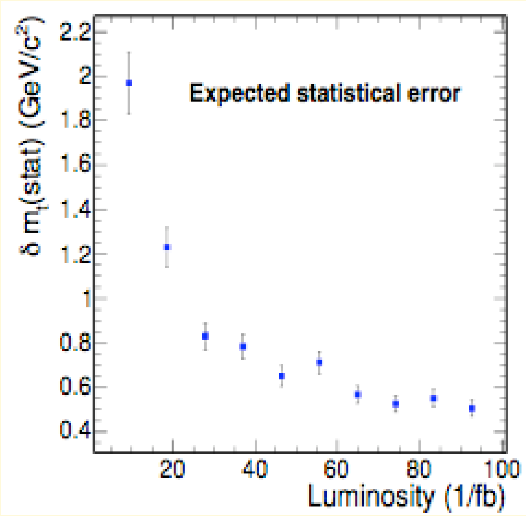
Study M($\mu^+ \mu^- \ell$) vs M_{top}



CMS TDR

TH source	δM_{top} (GeV)	EXP source	δM_{top} (GeV)
Λ_{QCD}	0.31	electron E scale	0.21
Q^2	0.56	muon E scale	0.38
Scale def	0.71	electron E resol	0.19
b-quark frag	0.51	muon p resol	0.12
light-jet frag	0.46	Jet E scale	0.5
MB/UE	0.64	Jet E resolution	0.05
PDF	0.28	Background	0.21
Total	**1.37**	Total	**0.54**

Statistical uncert



Total systematics: 1.47 GeV

LHC as a top factory (1Hz@10^{33}): study of top properties, a new domain only scratched at the surface by the Tevatron

1) tbW coupling

$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)\, t\, W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(g_L P_L + g_R P_R)\, t\, W_{\mu}^{-} + \mathrm{h.c.}$$

Probe anomalous couplings by measuring lepton FB asymmetry in the top rest frame

1σ limits:	min	max
V_R	-0.10	0.16
g_L	-0.08	0.05
g_R	-0.02	0.02

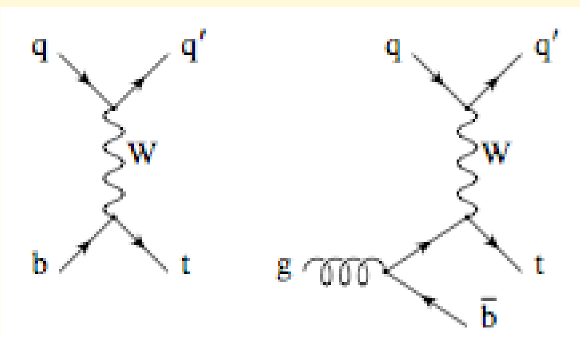
implications for various BSM models are being studied

2) FCNC decays

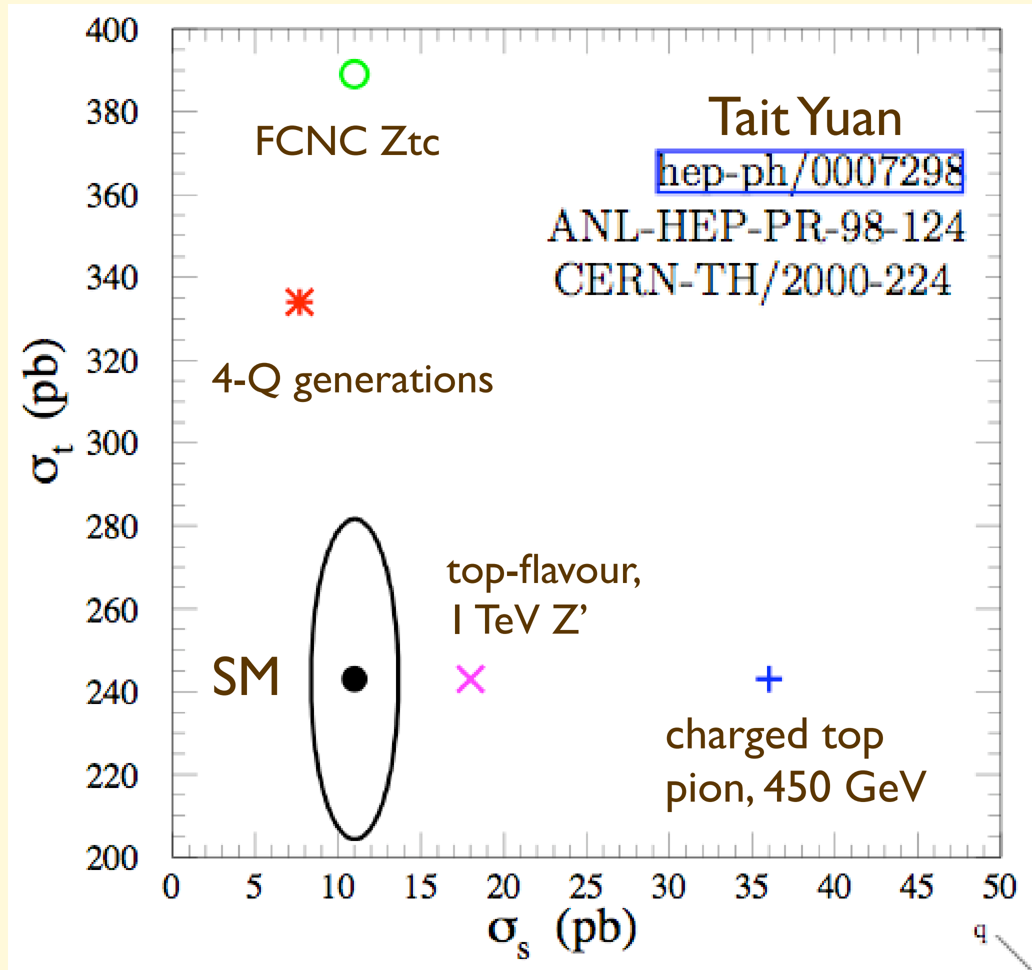
BR	SM	2-Higgs	SUSY RPV	exotic Qs	**Today**	**LHC 100fb-1**
$t \to qZ$	10^{-13}	$\leq 10^{-6}$	$\leq 10^{-4}$	$\leq 10^{-2}$	≤ 0.08 (LEP)	$\leq 6.5 \times 10^{-5}$
$t \to q\gamma$	10^{-13}	$\leq 10^{-7}$	$\leq 10^{-5}$	$\leq 10^{-5}$	≤ 0.003 (HERA)	$\leq 1.8 \times 10^{-5}$
$t \to qg$	10^{-11}	$\leq 10^{-5}$	$\leq 10^{-3}$	$\leq 10^{-4}$	≤ 0.29 (CDF)	$\leq 4.3 \times 10^{-4}$

Single top production

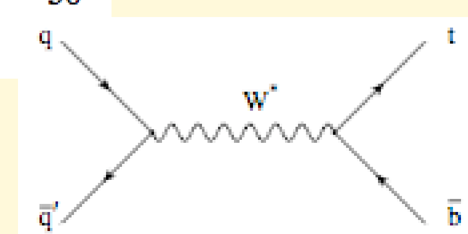
- Electroweak process (contrary to standard top-pair production)
  - sensitive to the tbW vertex, possible anomalous couplings



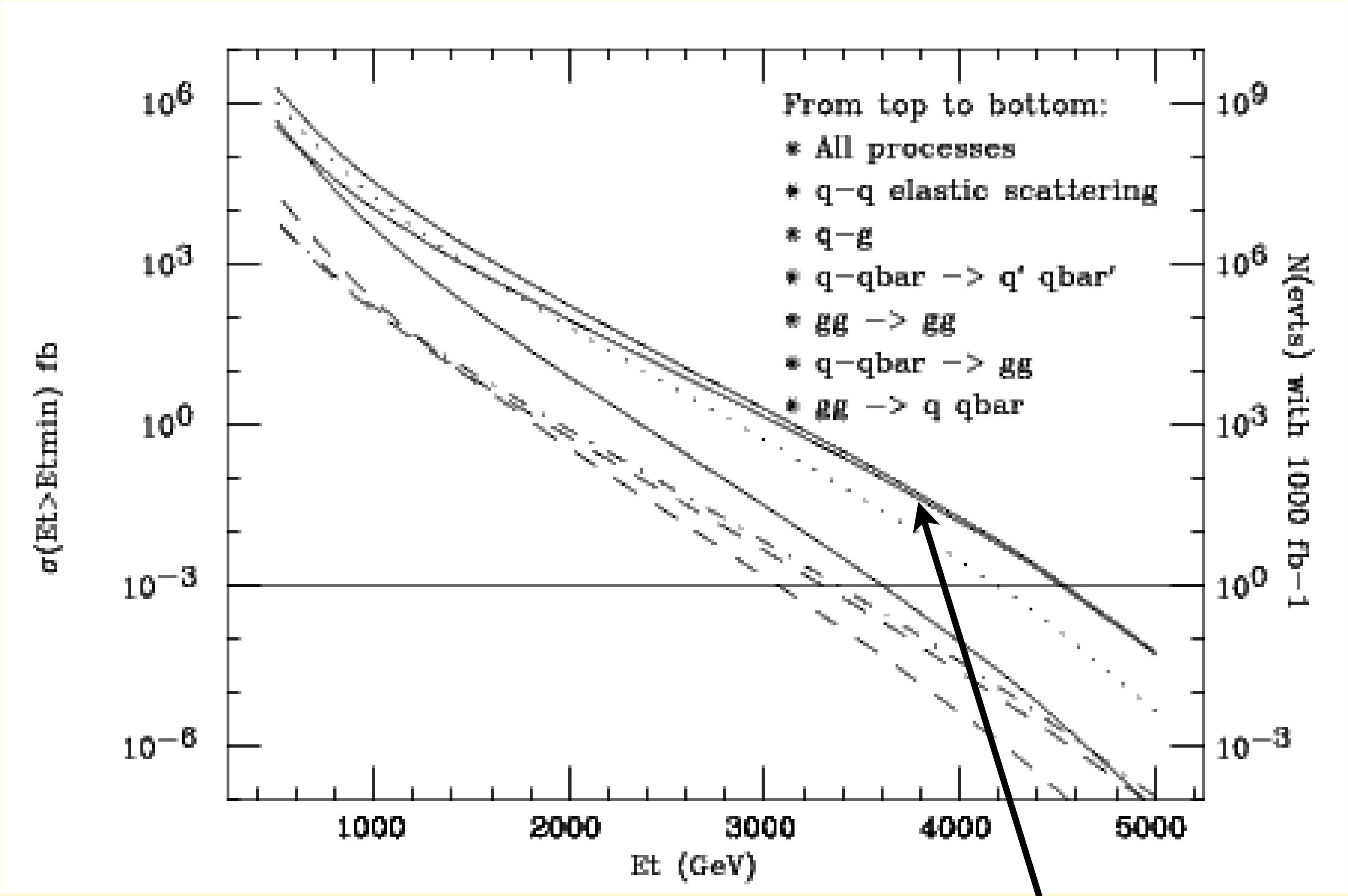
t-channel production rate



s-channel production rate



Jet production

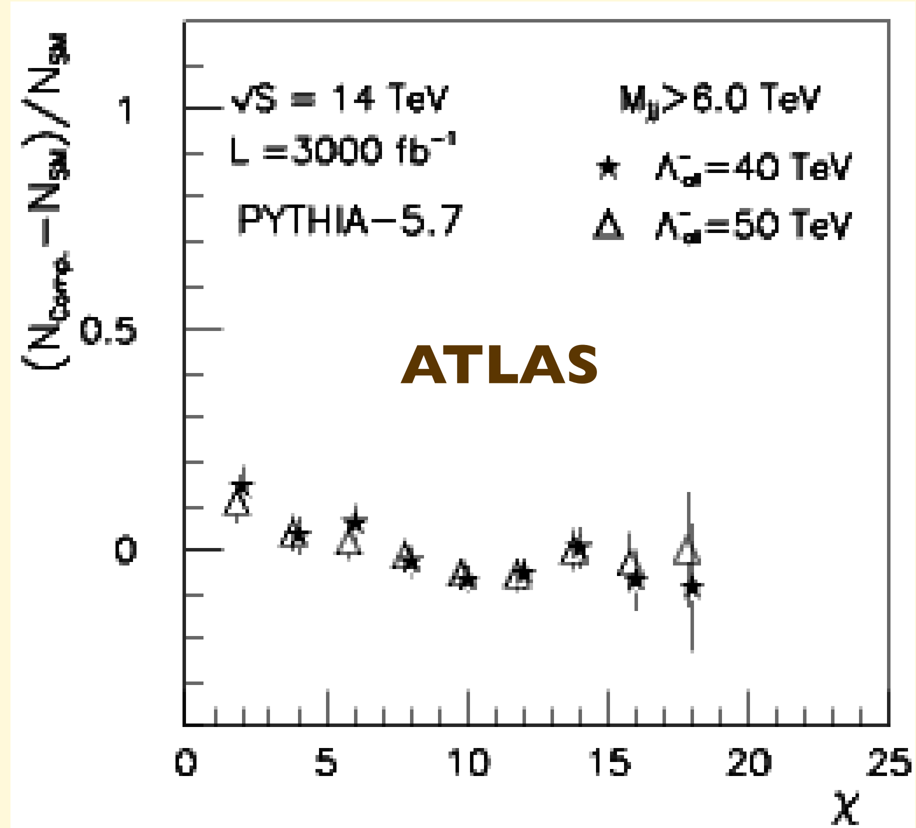


Mostly qq elastic scattering at the highest E_T

Quark substructure using jets

Study the distribution, as a function of the dijet invariant mass, of:

$$\chi = \frac{1 + |\cos\theta|}{1 - |\cos\theta|}$$

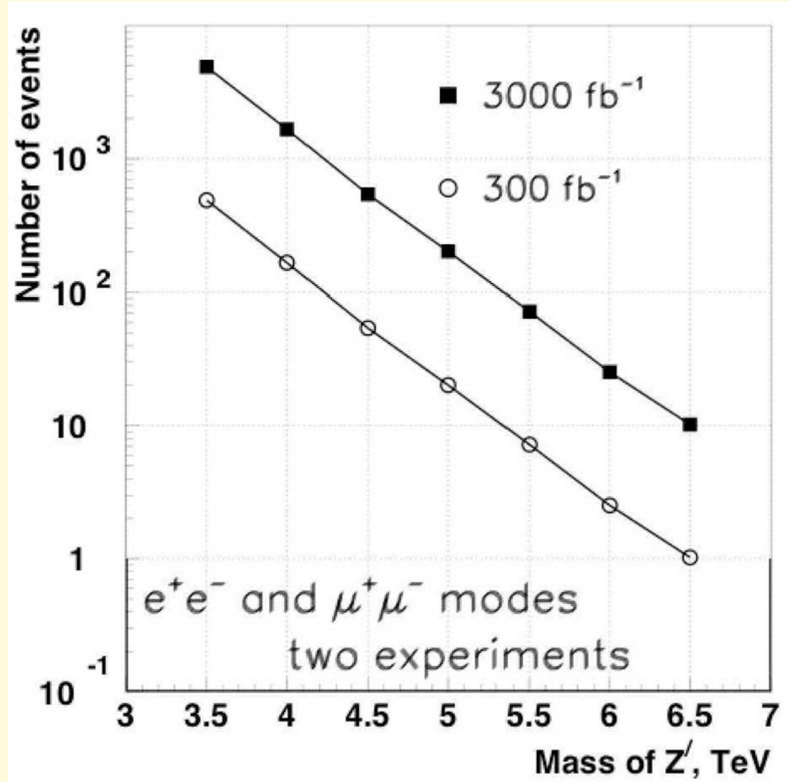


Current PDG limit
(Tevatron run I):

$\Lambda^{95\%}$ (TeV) > 2.7 TeV

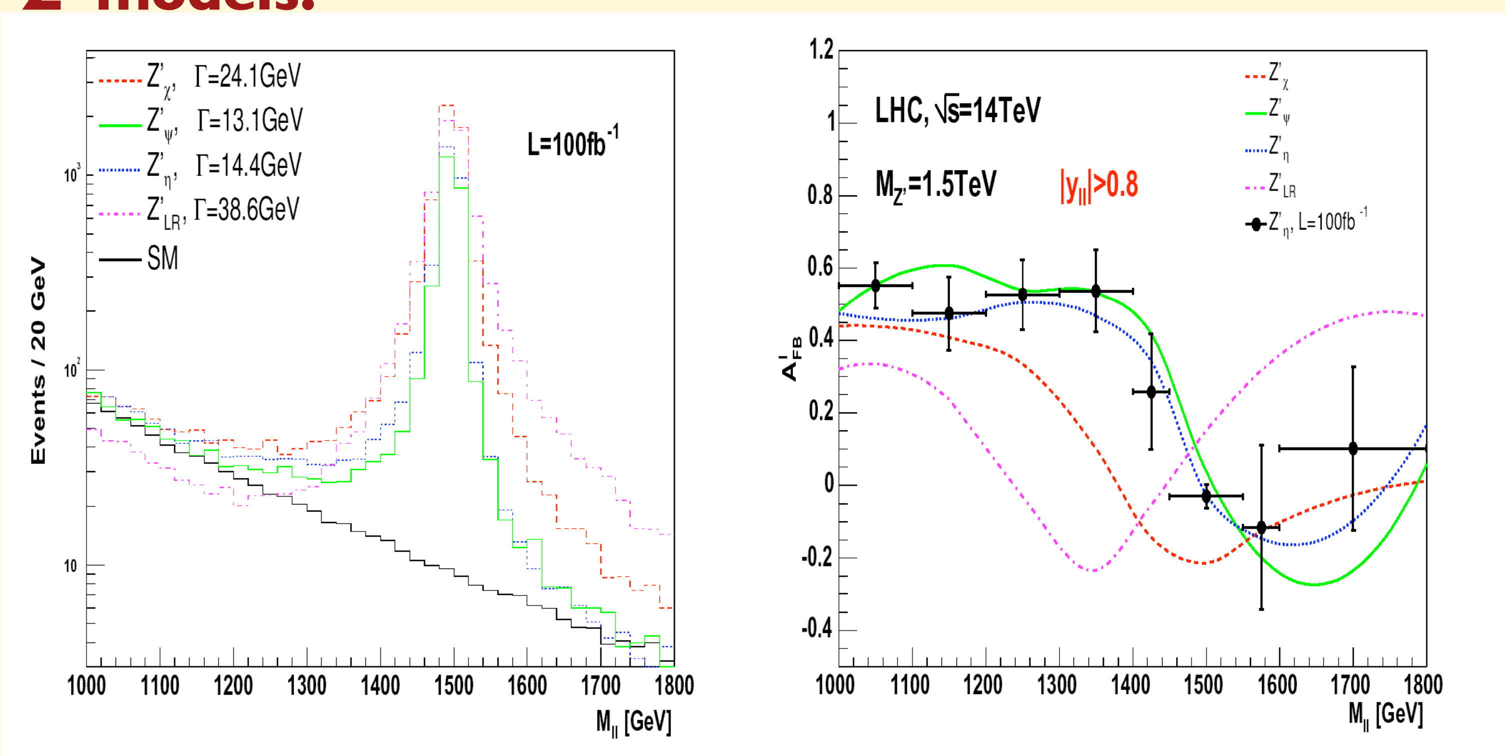
(D)(S)LHC	14 TeV, 300 fb^{-1}	14 TeV, 3000 fb^{-1}	28 TeV, 300 fb^{-1}	28 TeV, 3000 fb^{-1}
$\Lambda^{95\%}$(TeV)	**40**	**60**	**60**	**85**

Searching new forces: Z'



100 fb^{-1} discovery reach up to ~ 5.5 TeV

Differentiating among different Z' models:



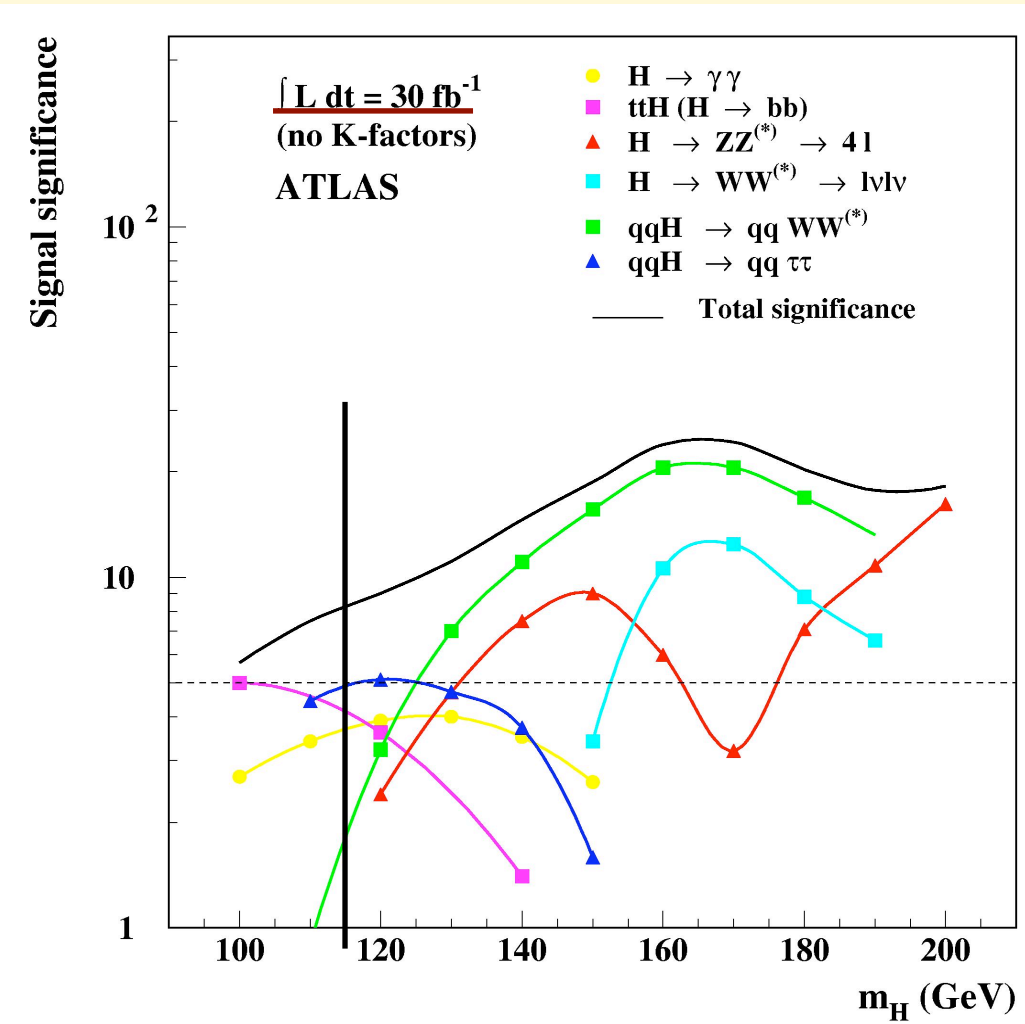
100 fb^{-1} model discrimination up to 2.5 TeV

What's the LHC going to tell us about EWSB?

The first conclusive YES/NO answer to the question of whether the SM Higgs mechanism is valid or not

IF SM, then the Higgs boson will be seen with $\int L \leq 15\ fb^{-1}$

- $115 < m_H < 200$ from LEP and EW fits in the SM
- SM production rates well known
- SM decay rates well known
- Detector performance for SM channels well understood

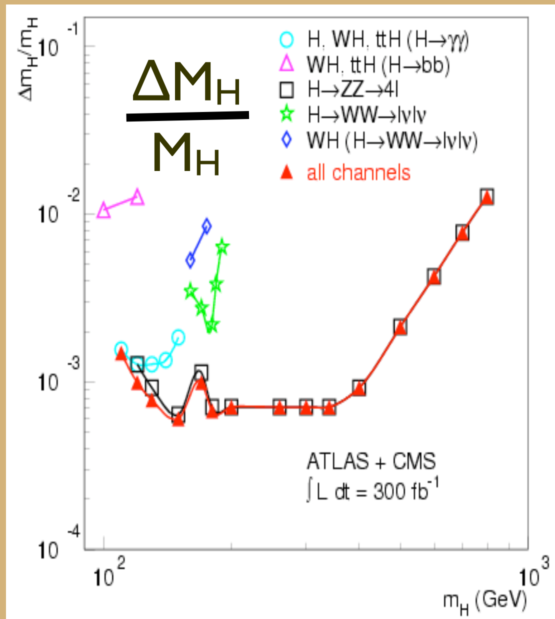


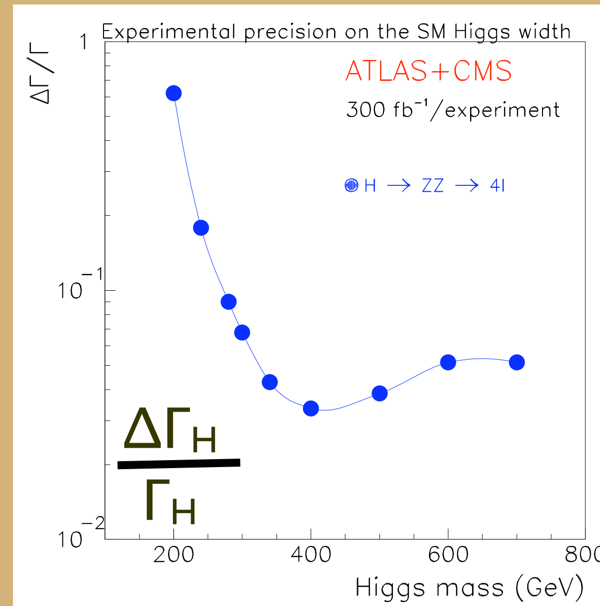
ATLAS, **10 fb⁻¹** m_H=115	H→γγ	ttH→ttbb	qqH→qqττ
S	130	15	10
B	4300	45	14
S/√B	**2**	**2.2**	**2.7**

Combined S/√B = $4^{+2.2}_{-1.3}$

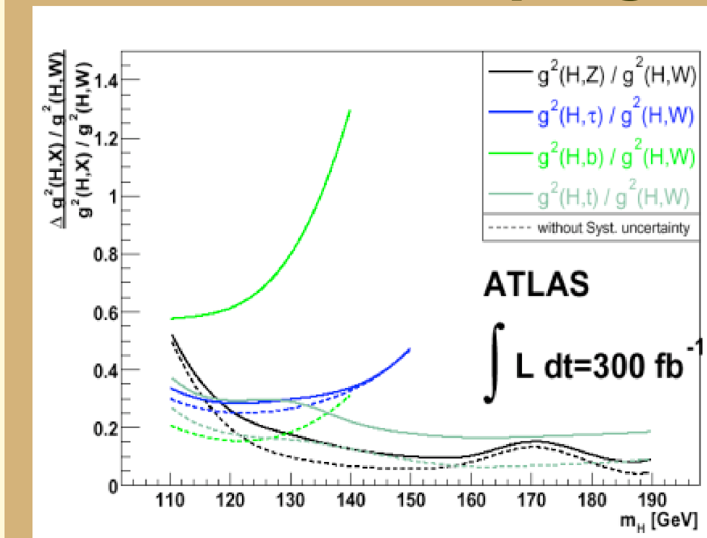
All very challenging channels, small individual significance ⇒ lengthy analyses

Measurement of Higgs properties ($\int L > 100\ fb^{-1}$)

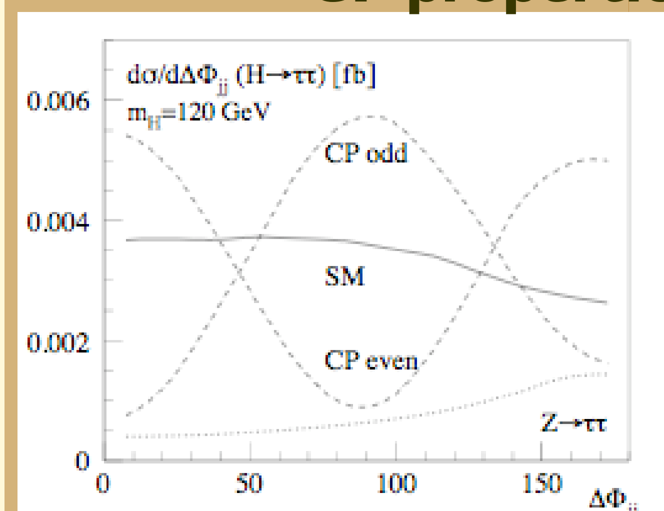


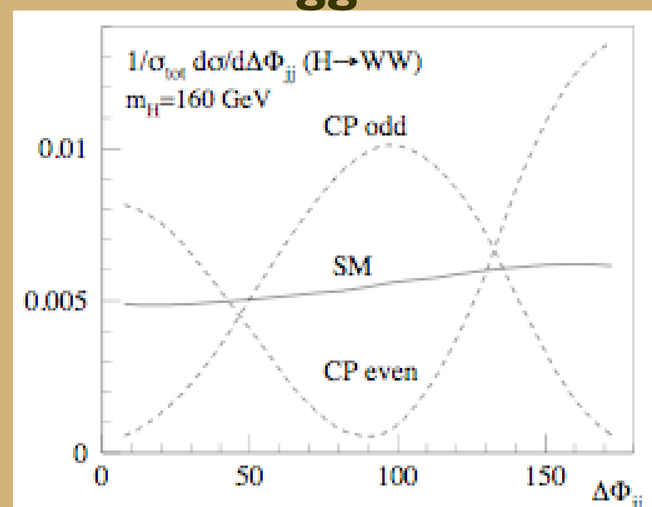


Ratios of couplings



CP properties of the Higgs

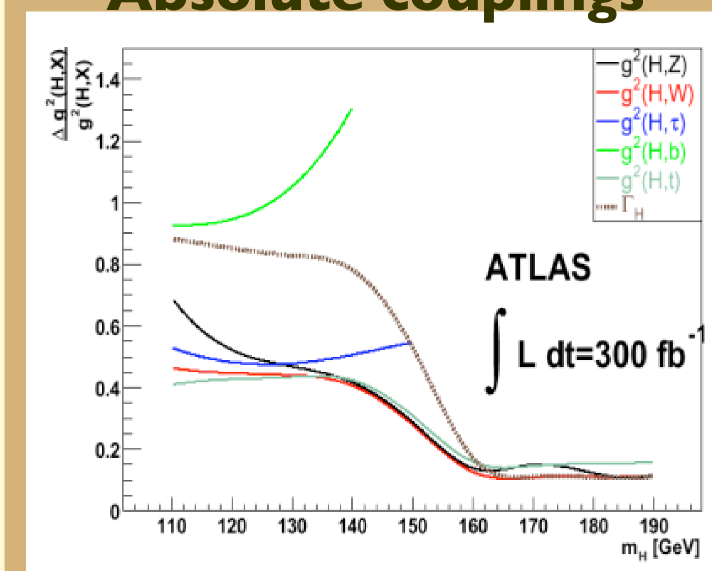




Study the dijet azimuthal correlations in vector-boson fusion Higgs production, **qq → qq H**

(Plehn, Rainwater, Zeppenfeld)

Absolute couplings

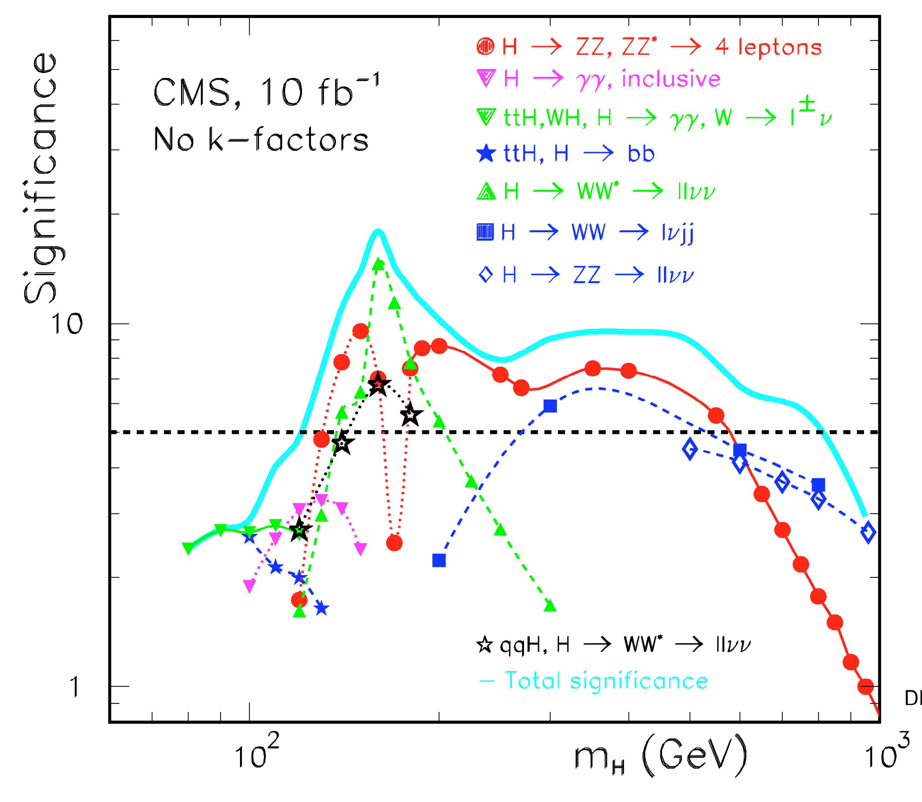


IF seen outside SM mass range:

- new physics to explain EW fits
- problems with LEP/SLD data (M.Chanowitz)

In either case,

- easy prey with low luminosity up to ~ 800 GeV!



IF NOT SEEN UP TO m_H~800 GEV:

$\sigma < \sigma_{SM}$:
reduced couplings ⇒ **new physics**

BR(H→visible) < BR_{SM}:
reduced couplings ⇒ **new physics**

m_H>800 GeV:
expect WW/ZZ resonances at $\sqrt{s}$ ~ TeV ⇒ **new physics**

It may take longer to sort out these scenarios, but the conclusion about the existence of BSM phenomena will be unequivocal

Ex.: MSSM Higgs discovery potential

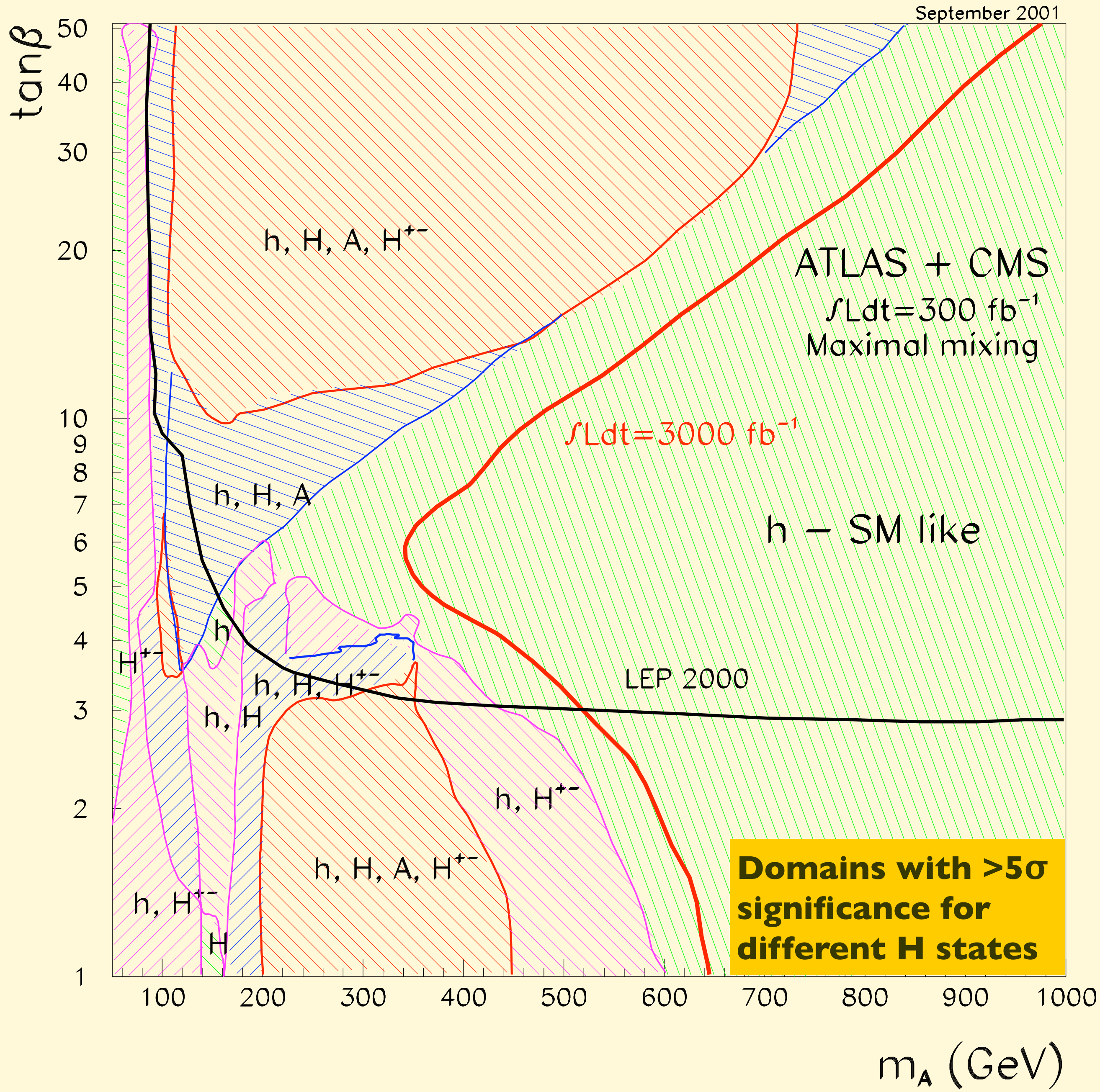
$h^0, H^0, A^0, H^\pm$

MSSM specific decays:

- $A/H \to \mu\mu, \tau\tau, tt$
- $H \to hh$
- $A \to Zh$
- $H^\pm \to \tau\nu$

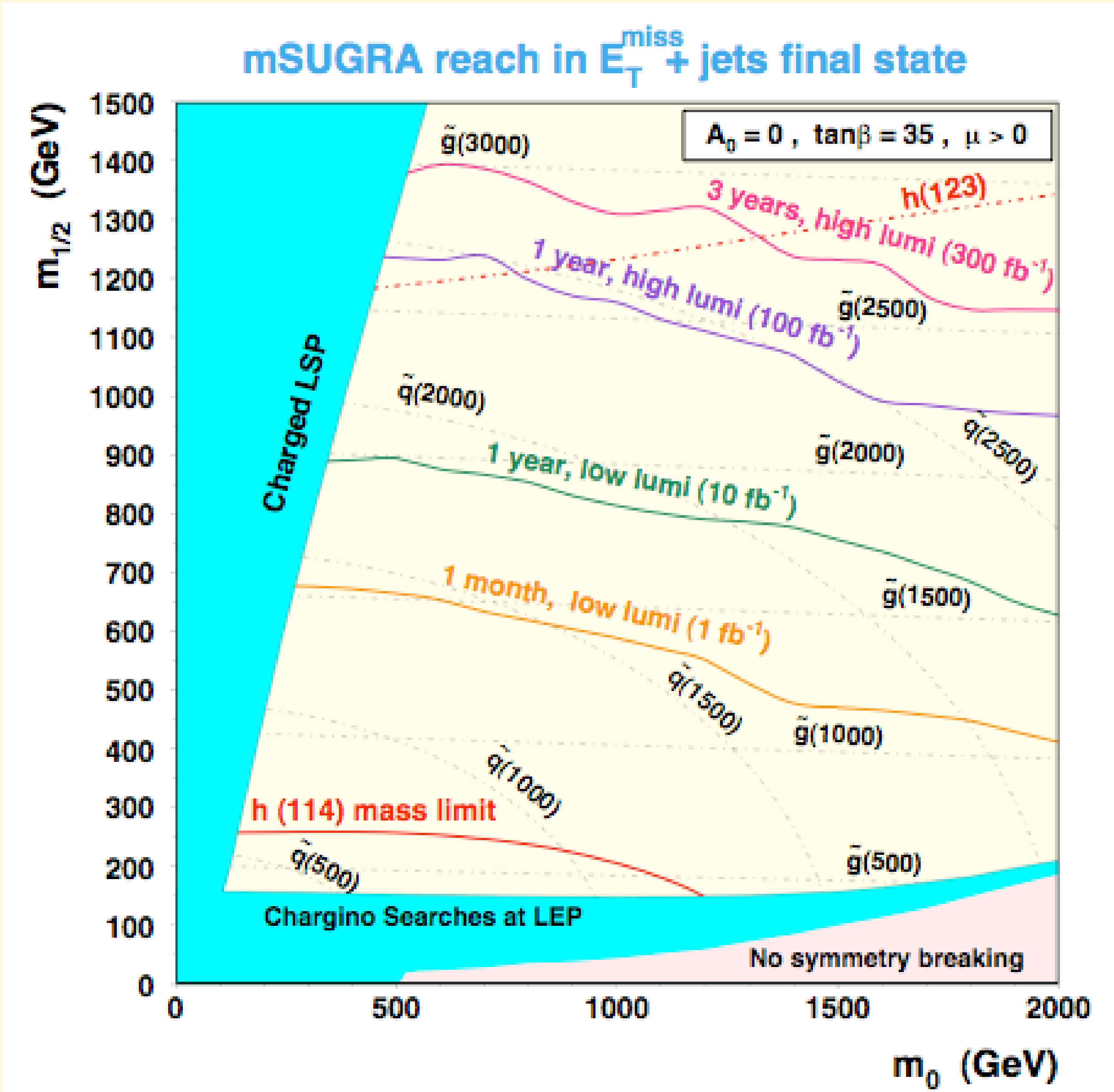
If SUSY particles light enough:

- $H/A \to \chi_2^0 \chi_2^0 \to \chi_1^0 \chi_1^0 + 4\text{lept's}$
- h produced in cascade decays



Domains with >5σ significance for different H states

Inclusive Supersymmetry searches



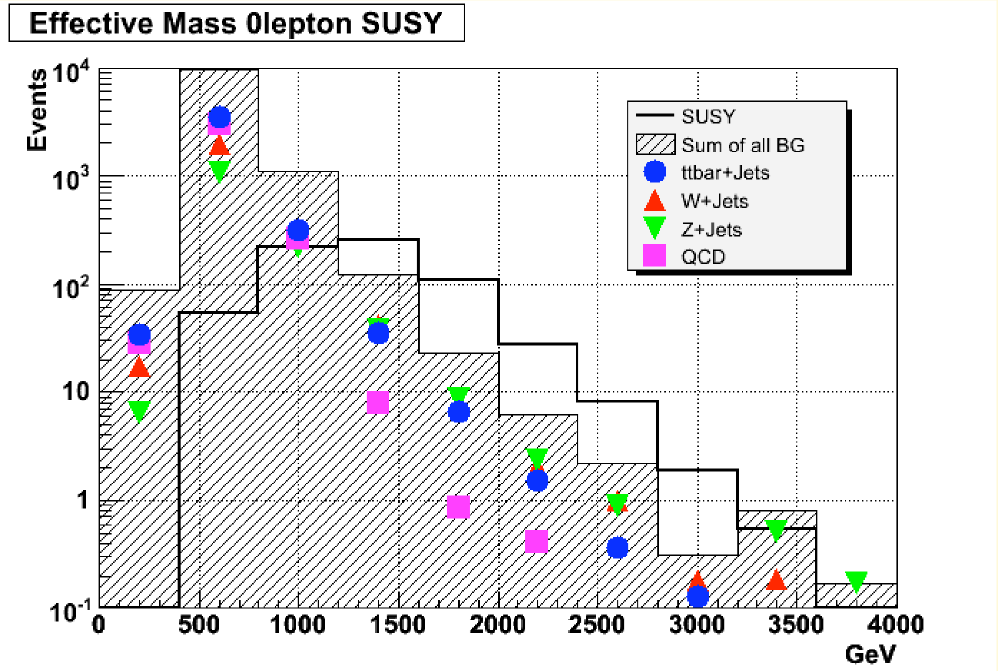
Expected reach in the overall mass scale for gluinos and squarks:

1fb-1 ⇒ 1-1.5 TeV

10fb-1 ⇒ 1.5-2 TeV

100fb-1 ⇒ 2.5 TeV

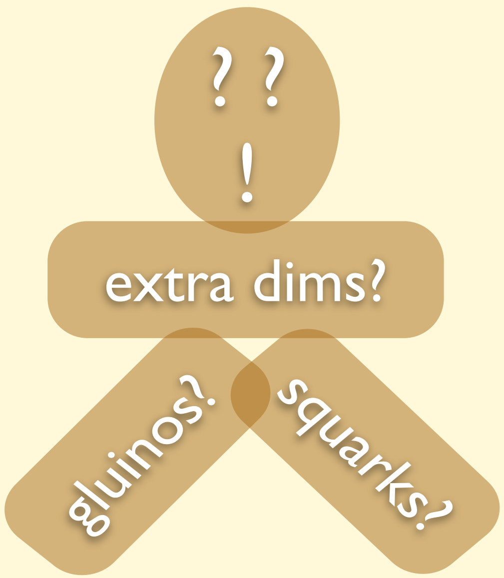
At the beginning, the experiments will give us just this:



$$M_{eff}\,(\mathrm{GeV}) = \sum_{i=1,4} E_T\,(i) + E_T^{miss}$$

The big challenge for the PDG:
how do we encode this result in the RPP listings?

Current format of RPP listings for *Searches* is a list of limits on the parameters of specific models, in a situation where no signal has been seen. In presence of a signal compatible with many interpretations, as with SUSY early on, the scheme breaks down.



Providing a clear summary and assessment of the new findings of the LHC, to enable the community to contribute to their interpretation, will be the single greatest challenge to the future PDG

So far, time between RPP editions has been sufficient to allow the clarification of the meaning of a given discovery, and the PDG could rely on the published accounts to fill its entries and provide the community with a repository of digested data*.

On the contrary, for the LHC findings it may take years before a conclusive interpretation is found.

Which role should the PDG play during this interim?

* there have clearly been a few exceptions!

With time (typically $O(100\ fb^{-1})$), the reconstruction of individual SUSY states at the LHC will be possible, and the RPP will acquire a Volume 2:

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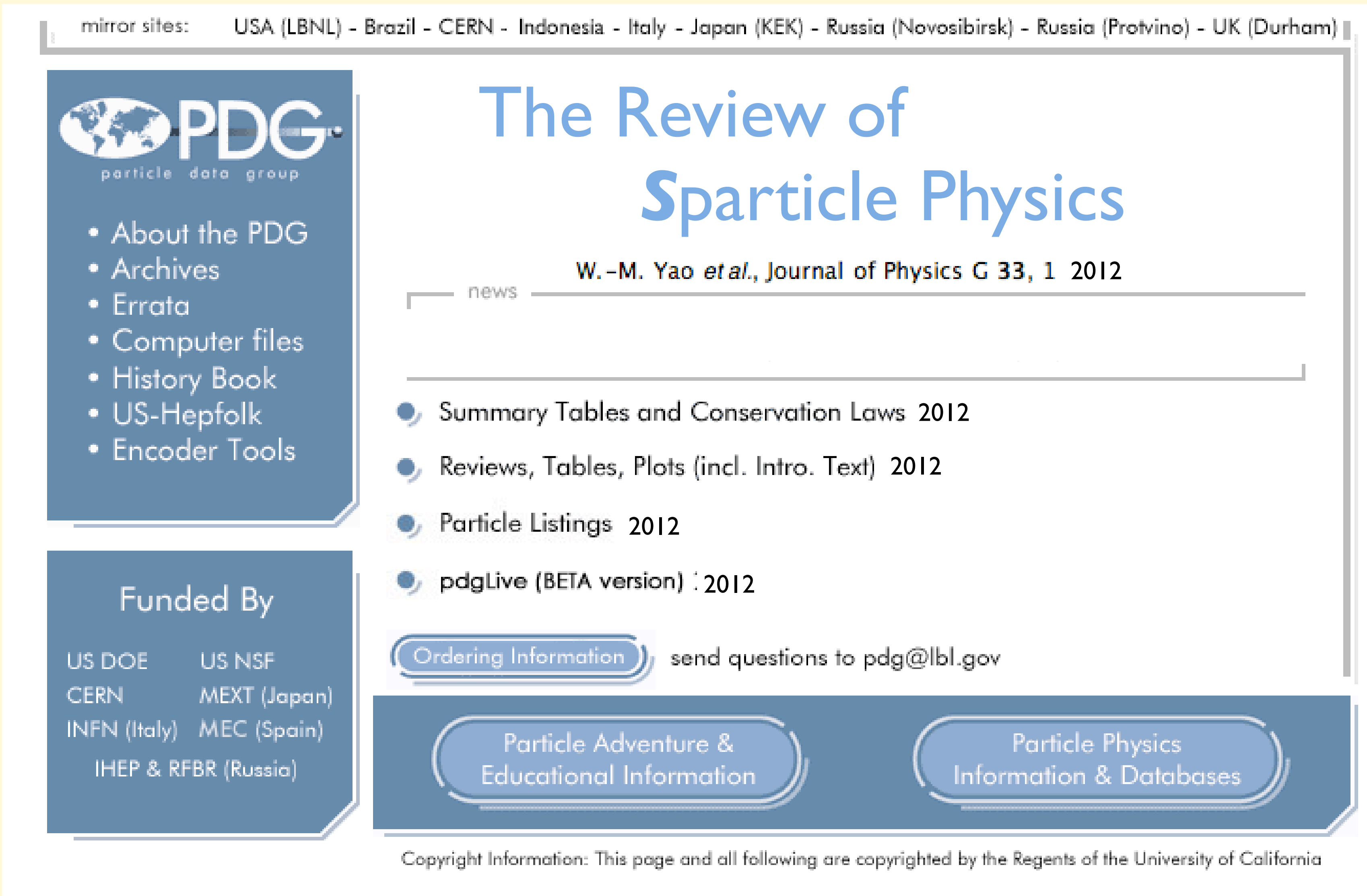

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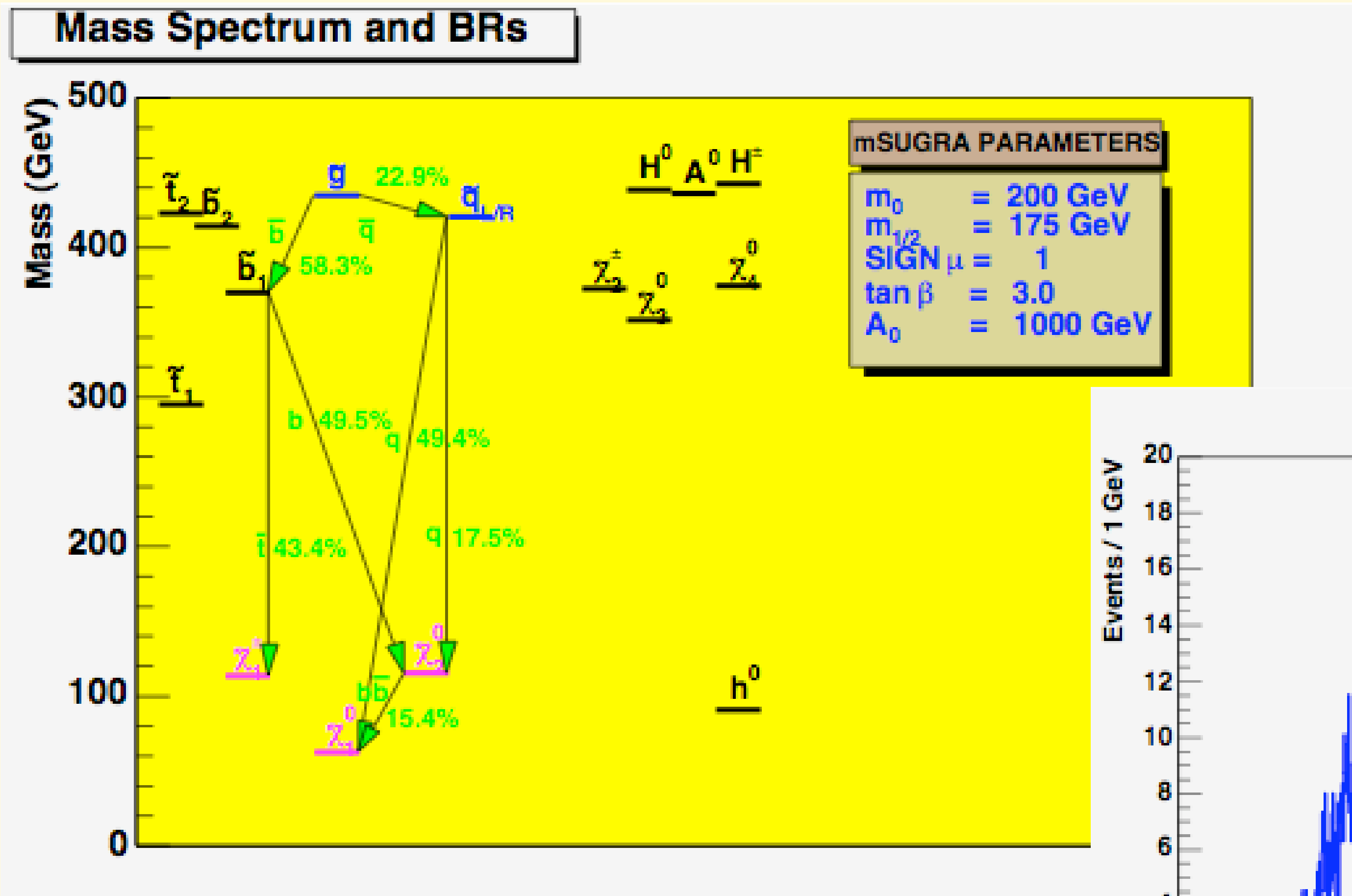
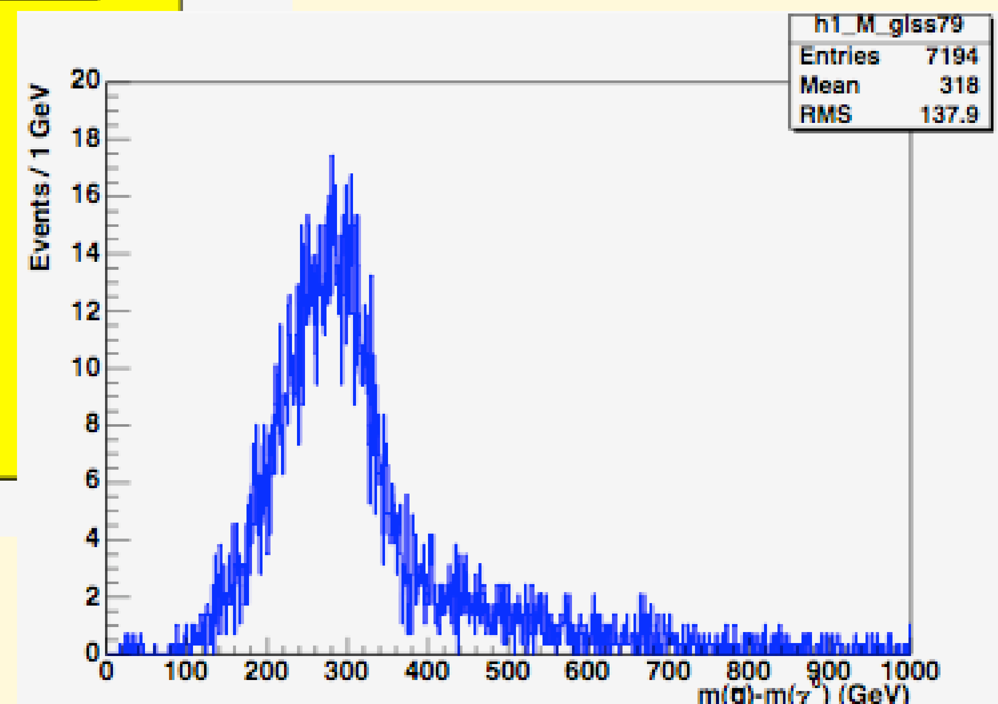
Example, sbottom from gluino decays

$$pp \to \tilde{q}\,\tilde{g}\,, \quad \tilde{g} \to b\,\tilde{b}^* \to b\,\bar{b}\,\chi^0_2 \to b\,\bar{b}\,l^+ l^- \chi^0_1$$

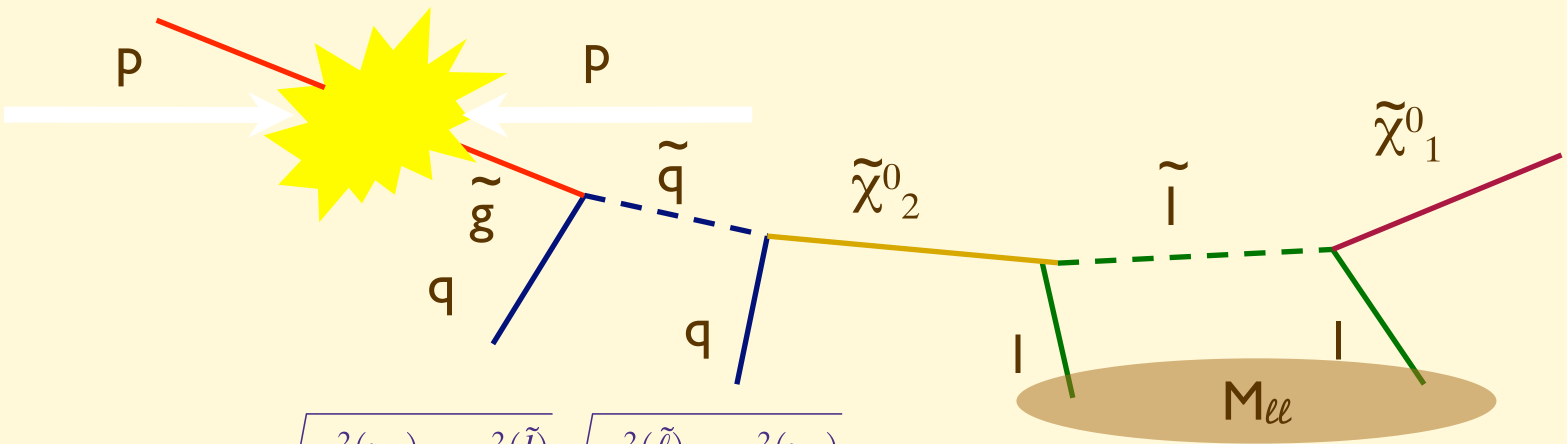




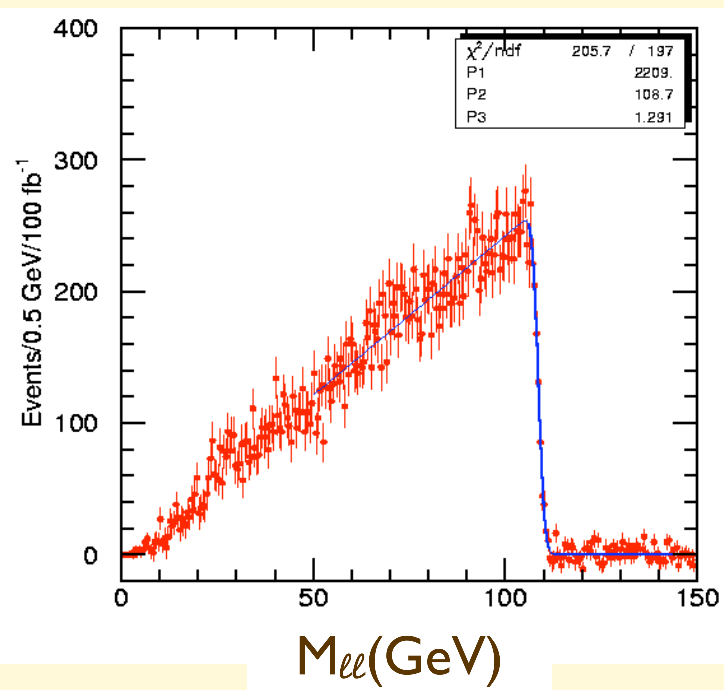
m(bbl)~m(gluino) - m(χ^0)

Example, slepton reconstruction

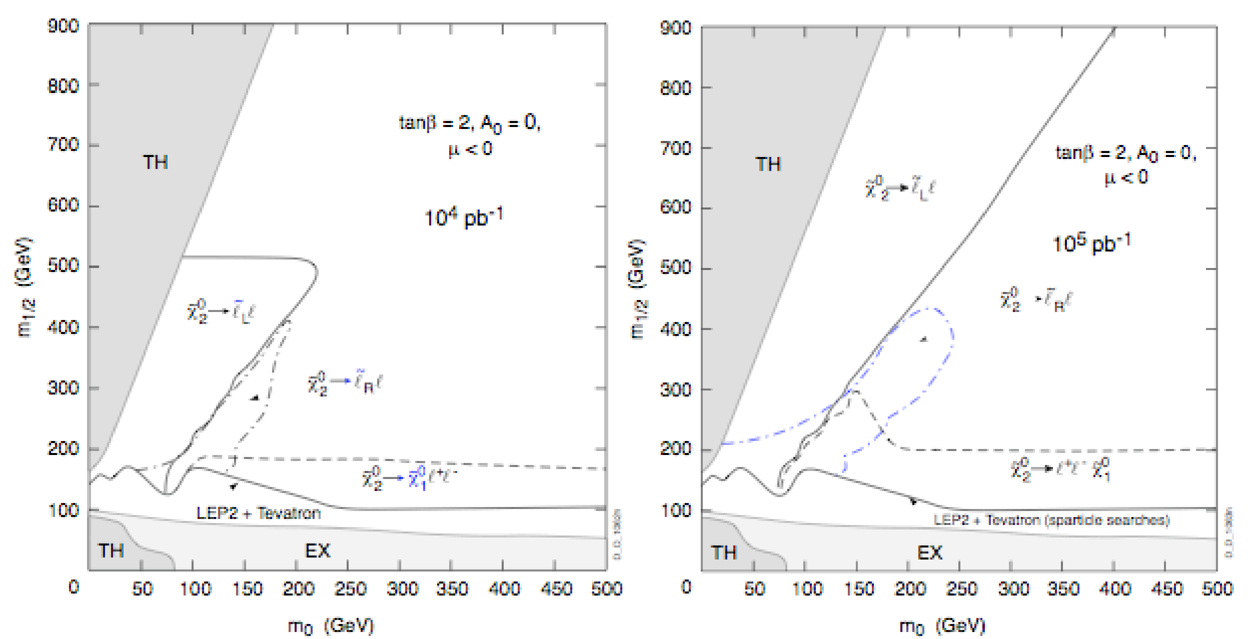
$$\chi_2^0 \to \tilde{\ell}^{\pm}\ell^{\mp} \to \chi_1^0 \ell^+\ell^-$$



$$\max\left(m(\ell^+\ell^-)\right) = m(\chi_2)\sqrt{\frac{m^2(\chi_2)-m^2(\tilde{l})}{m^2(\chi_2)}}\sqrt{\frac{m^2(\tilde{\ell})-m^2(\chi_1)}{m^2(\ell)}}$$



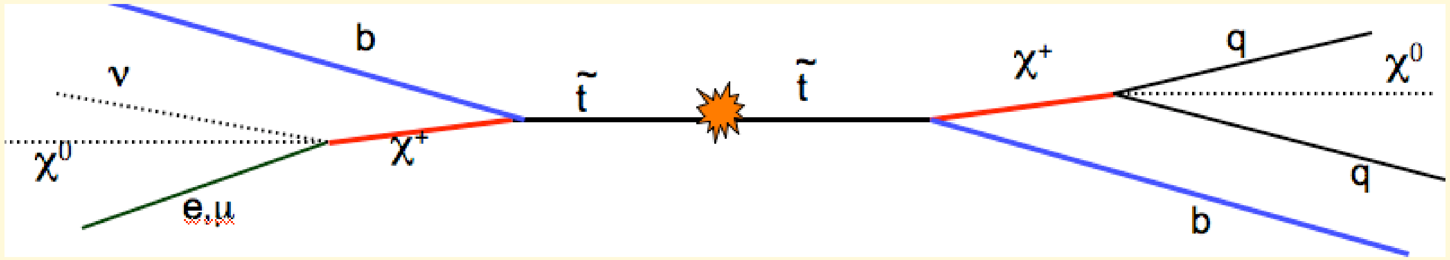
Dilepton endpoints observable over wide range of mSUGRA parameter space scanned with fast simulation [CMSSUSY]:



Example, light stop

Consistent with mH, DM, EW scale baryogenesis, EDMs, etc

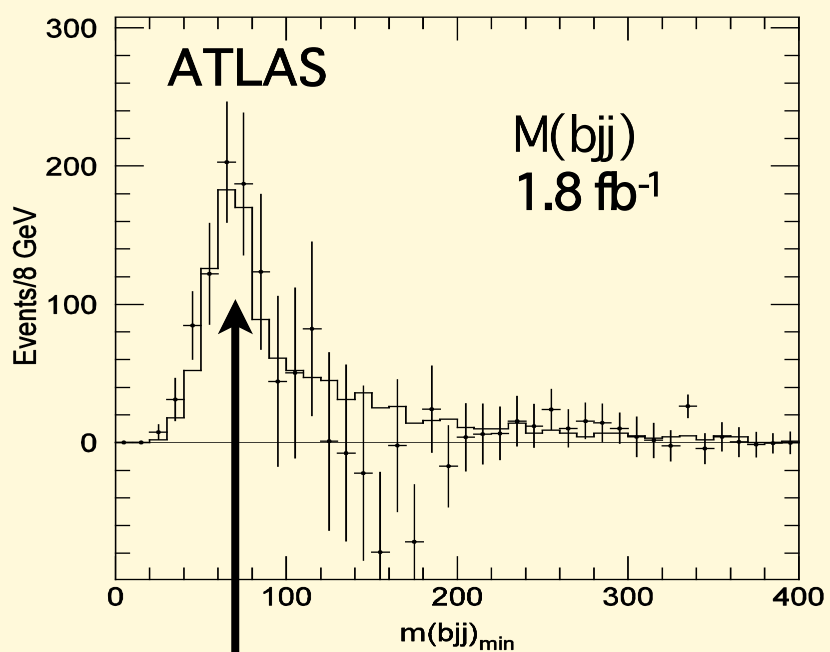
Mass spectrum (GeV)	
t_1	137
t_2	1510
g	948
u,e	~10000
$\chi^0{}_1$	58
$\chi^0{}_2$	112
$\chi^+{}_1$	111
h	116

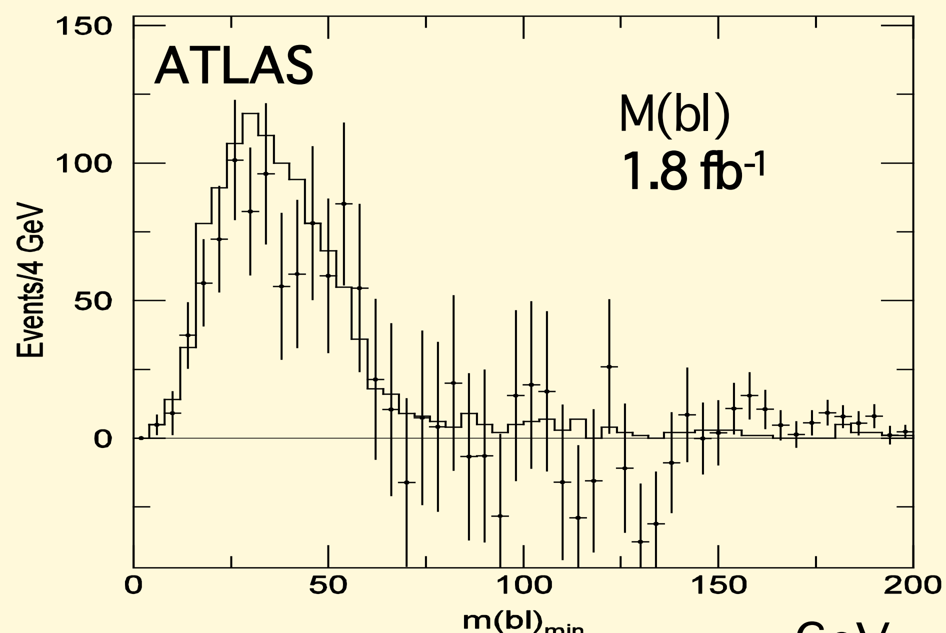


After ttbar and W+jets bg subtraction:

Points: simulated data

Histo: MC truth





GeV

m(stop)-m(χ^0) ~ 79 GeV

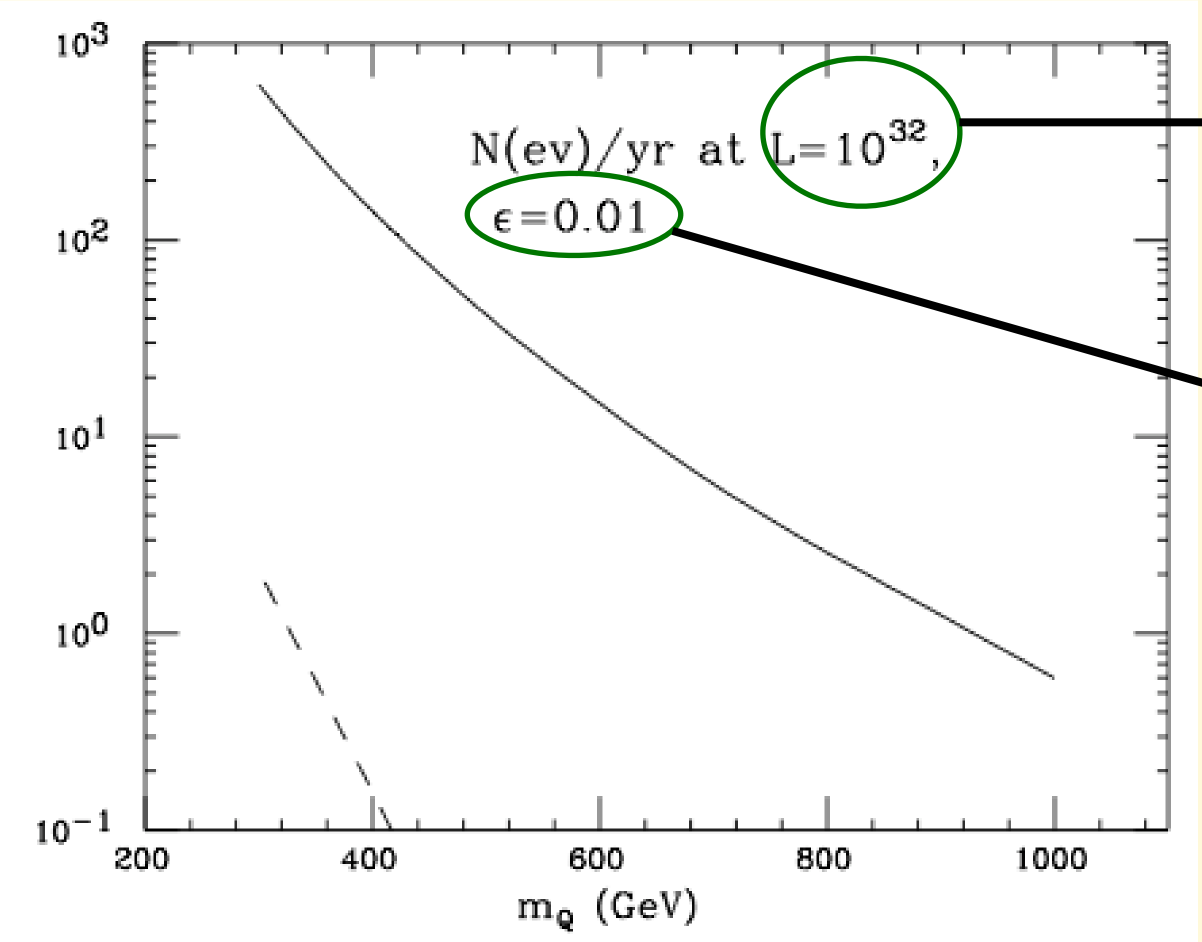
Examples of measurement accuracies, for a specific model:

Measurement	Expected value (GeV)	Error (%) $300\ \text{fb}^{-1}$
m_0	100 GeV	± 3
$m_{1/2}$	300 GeV	± 1.3
$\tan\beta$	2.1	± 2
m_h	93	± 0.2
$m_{\ell^+\ell^-}$ end-point	109	± 0.2
$m_{\tilde{\ell}_R}$	157	± 0.3
$m_{\tilde{\ell}_L}$	240	± 1
$m_{\tilde{q}_L}$	690	± 1
$m_{\tilde{q}_R}$	660	± 1.5
$m_{\tilde{g}}$	770	± 1.5
$m_{\tilde{t}_1}$	490	± 10

How long will it take for new physics to show up ?

Production rates for new heavy objects in the region of the asymptotic Tevatron reach are 10^3 times larger at the LHC!

E.g.: production of new massive heavy quark pairs:



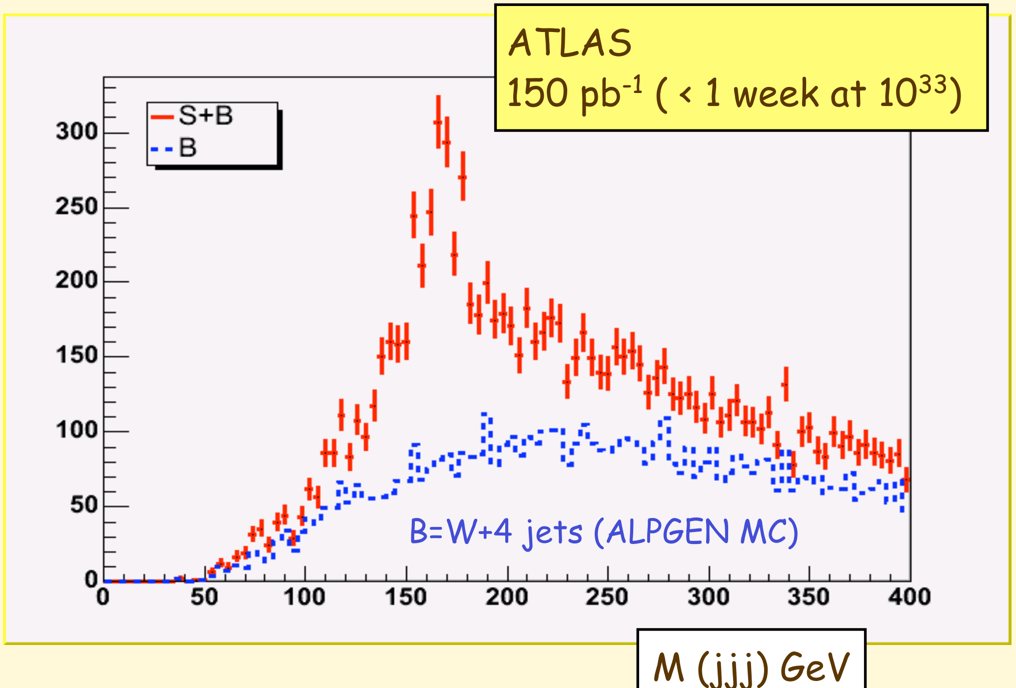
1% of L_{max} for the LHC, (as in SppS and Tevatron early runs), close to L_{max} for Tevatron

(assume a 1% signal efficiency)

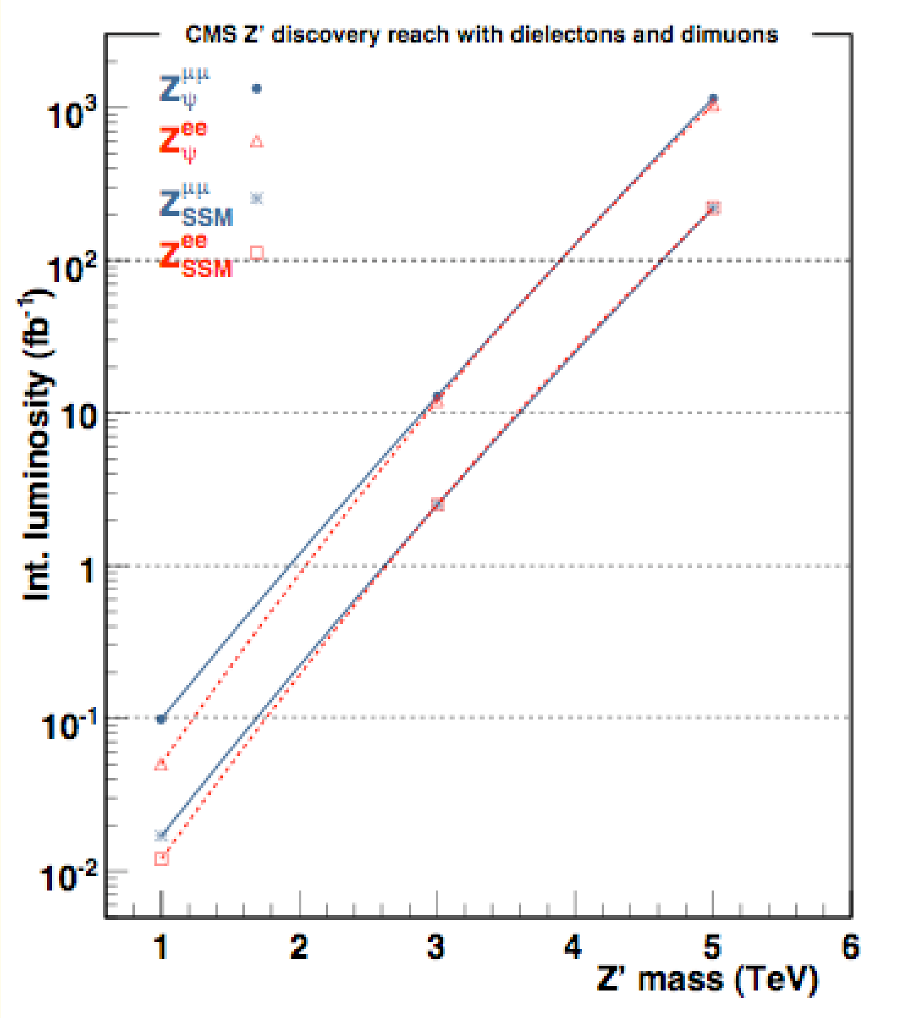
N.B.: rates for gluino production are roughly a factor of 10 larger than for HQs

New physics in mass domains never probed before could be on tape within few weeks of run at low luminosity in 2008

Examples

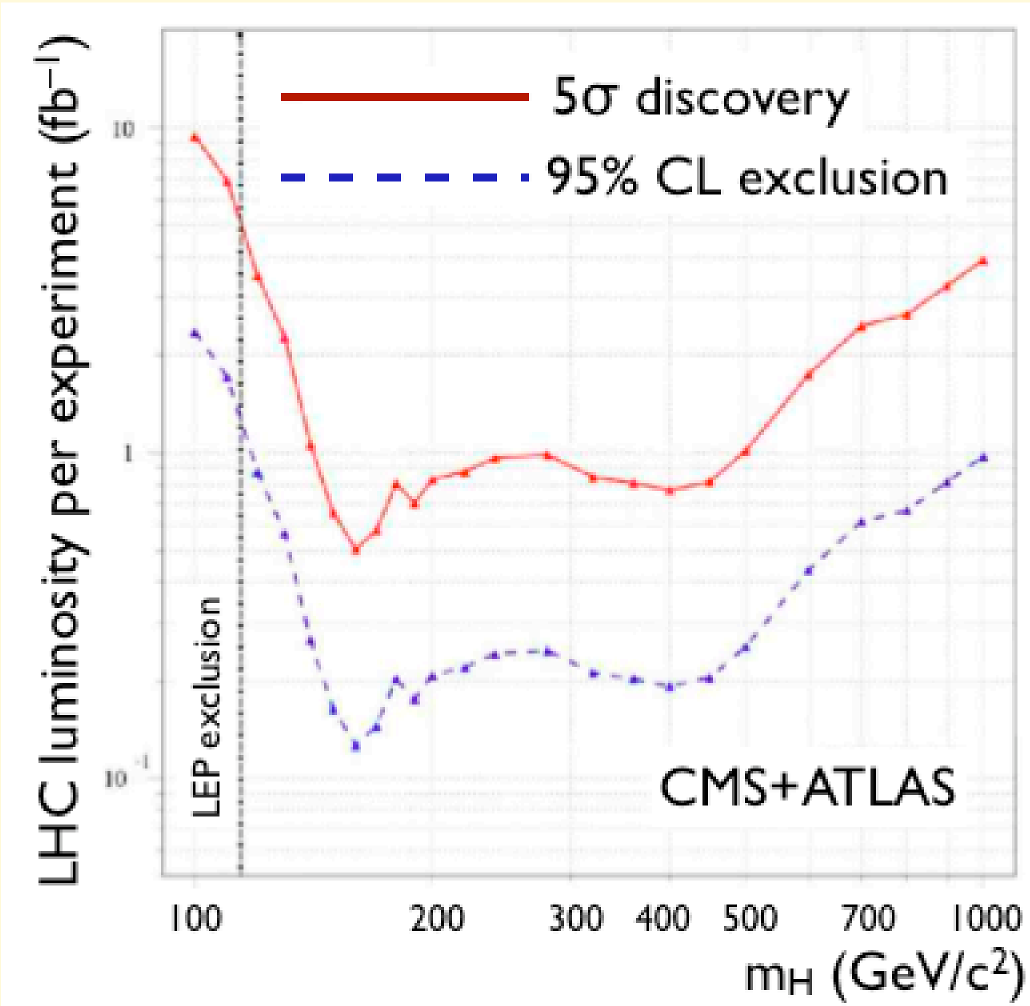


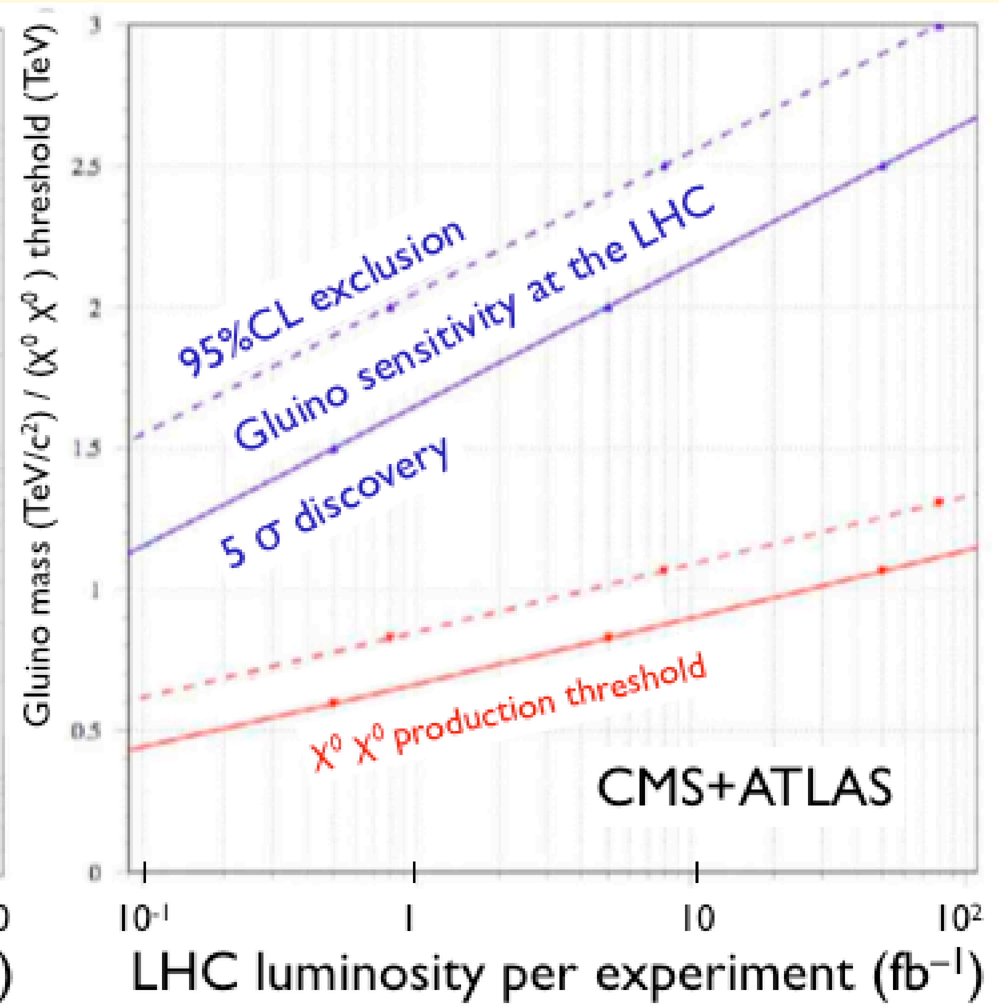
Time	Events at 10^{33}	Stat. error δM_{top} (GeV)	$[\delta\sigma/\sigma]$stat
1 year	3×10^5	0.1	0.2%
1 month	7×10^4	0.2	0.4%
1 week	2×10^3	0.4	2.5%



Mass	N(events) / 10 fb^{-1}	Lum required for N_{ev} =10
1 TeV	~1600	~ 70 pb^{-1}
1.5 TeV	~300	~ 300 pb^{-1}
2 TeV	~70	~ 1.5 fb^{-1}

Summary of discovery potential for Higgs and SUSY with < 10 fb-1





By 2010 we should already have a good picture of TeV-scale physics!

EWSB and flavour

- EWSB is intimately related to flavour:
  - No EWSB ⇒ fermions degenerate ⇒ no visible flavour effect
- Why $m_{top} = g/\sqrt{2}\, m_W$ ($\Leftrightarrow y_{top} = 1$) ?
- In most EWSB models flavour plays a key role. E.g.:
  - Technicolor: killed by too large FCNC
  - Supersymmetry: large value of top mass drives radiative EWSB
  - In several extra-dim models the structure of extra dimensions -- driven by the need to explain the hierarchy problem of EWSB -- determines the fermionic mass spectrum
  - Little Higgs theories ⇒ top quark partners

The understanding of the origin and properties of **flavour** will be the natural next quest, after, or together with, the clarification of the origin and properties of **EWSB**

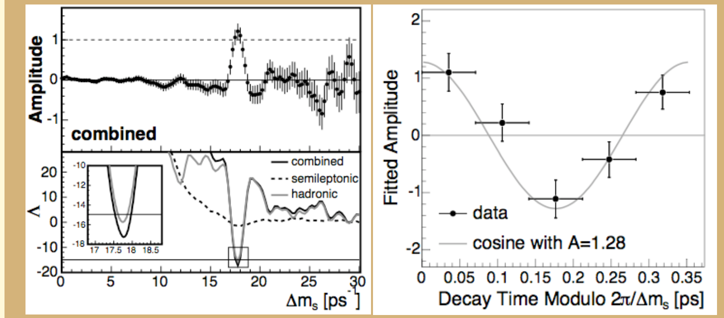
The LHC will play a key role in the study of flavour.

- Potential to observe $B_s \to \mu^+\mu^-$ down to the SM rate (BR~3.5×10^{-9})
- CPV phase in $B_s \to \phi\, K_s$, $\Delta\phi_s \sim 0.013$ rad $\to$ 3σ of SM $\phi_s = -0.04$
- Measure γ with 2.5° accuracy
- Highly sensitive searches for $\tau \to \mu ee$ in $D_s \to \tau\nu$
- LFV in SUSY decays: $\chi^0_2 \to \tilde{\ell}^{\pm}_2 \ell^{\mp}_3 \to \chi^0_1 \ell^+ \ell^-_2$
- etc.etc.etc.

But the full understanding of flavour will require a new generation of dedicated experiments, at the low-E, high-intensity frontier

- SuperB factories
- $K \to \pi\nu\nu/\pi\ell\ell$ decays
- EDMs, LFV, etc.etc.

Too late for B_s oscillations!



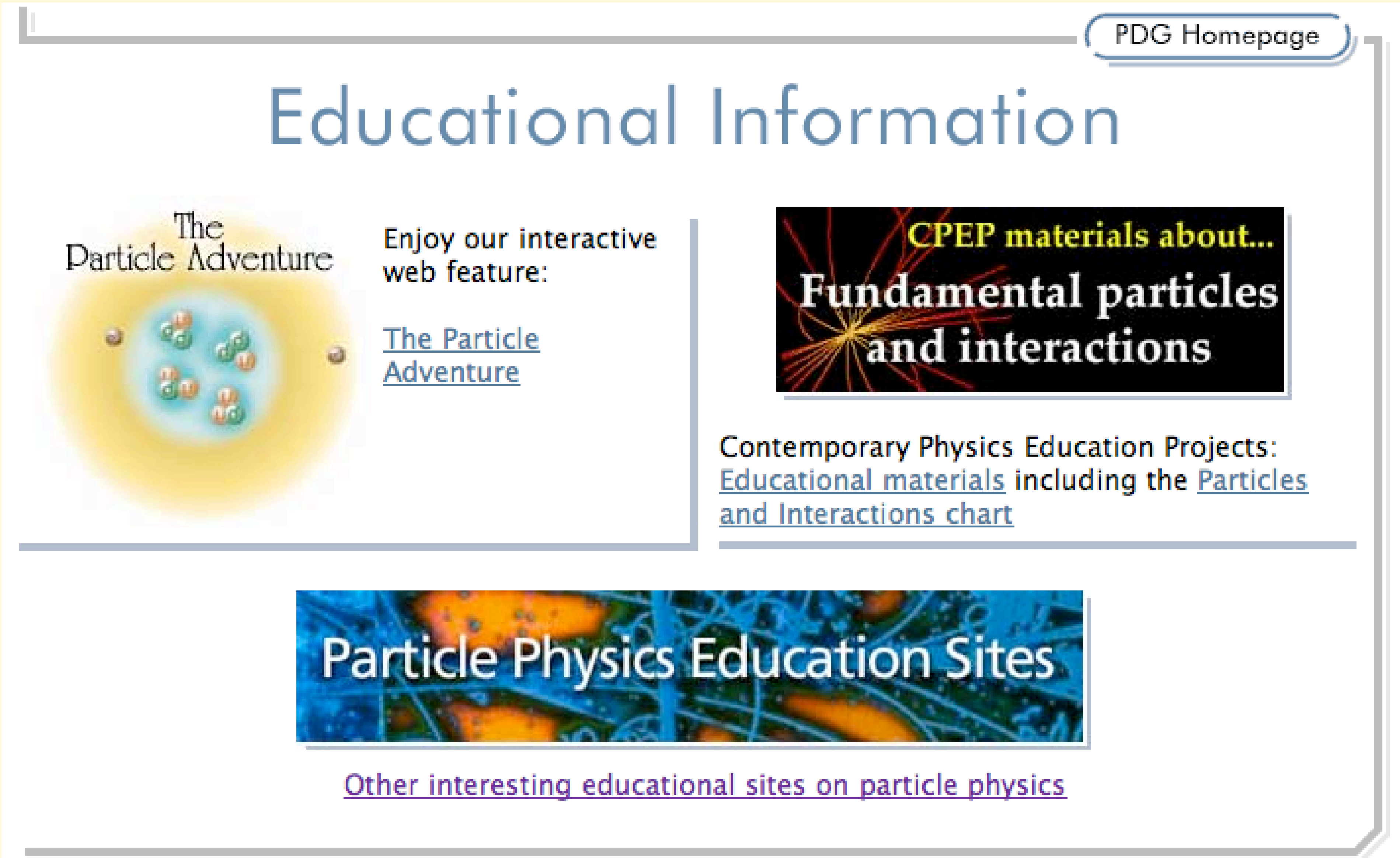
$\Delta m_s = 17.77 \pm 0.10_{stat} \pm 0.07_{syst}\ ps^{-1}$

5.4σ

C. Pauss, CDF,
FNAL Wine&Cheese,
Sept 22 2006

The 2nd biggest challenge to the PDG in the LHC era:

to transmit to society, as well as to our colleague scientists, the excitement of the new LHC discoveries



Conclusions

- You may have perceived a slight sense of optimism ......You may call it ***wishful thinking*** ☺ **....**
- It should be clear to everyone that the technical success of the LHC, and the emergence of the "expected" new phenomena, will be the ***conditio sine qua non*** for **a** future of particle physics (and of the PDG ...)
- Not seeing the Higgs – notwithstanding a nominal performance of accelerator and experiments – will be interesting to a theorist, but will NOT establish the required conditions for a step forward in the field (ILC, CLIC, etc)
- In the most optimistic scenarios, LHC findings will feed a renewed excitement in the field, to be exploited by investing in its fullest exploitation, as well as in a broad array of new experimental activities, not just at the HEF, but also at the low-energy, high-intensity frontier as well, fully engaging the whole particle physics community.